ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 10, No. 2. 2004

Theoretical Relations between Manufacture Factors of Covered Yarn and Coil Length of Covering Components

Donatas PETRULIS*

Department of Textile Technology, Kaunas University of Technology, Studentų 56, LT-3031 Kaunas, Lithuania

Received 30 August 2002; accepted 30 July 2003

Elastomeric covered yarns are widely used in stretch textiles. The current investigation is aimed at structure of covered yarn, which consists of polyurethane elastomeric multifilament core yarn and of two viscose multifilament yarns. In the article the theoretical relations between manufacture factors of covered yarn and coil length of covering components are proposed and analysed. A development of the earlier proposed predicting method of the coil length of covering yarns is used. The relations link the delivery speed of covered yarn, the rotational speed of the first and the second hollow spindles, and the core stretch ratio during wrapping on the one hand, and the coil length of covering components on the other hand. The evaluation of the influence intensity of each manufacture factor on coil length is proposed. The average partial differences of the functions are also found.
Keywords: covered yarn, yarn structure, coil length, manufacture factor.

INTRODUCTION

Covered yarns continued to be very popular over recent years [1 – 3]. These yarns, especially the structures with elastomeric core, are widely used in textile materials [4, 5]. Important market segments for elastomeric yarns are hosiery, swimwear, sportswear, underwear, and lace, as well as fashionable clothing [1 – 7]. Stretch knitted or woven fabrics can be made from covered yarns in which the core is elastomeric multifilament yarn and the covering is made from conventional (hard) multifilament yarns or fibres such as polyamide, viscose, etc.

The most common methods of producing elastic yarns are covering (hollow spindle technique), air covering, core spinning, and twisting [5 – 9]. In some types of the elastic yarns such as in covered yarns and in differential-twist wrapped yarns, there are the components which have a spiral shape.

The differential-twist wrapped yarn consisting of a core yarn and a wrapping yarn is proposed in [10]. This yarn has a particular differential-twist structure, caused by the different twists and twist directions between the wrapping yarn and the core yarn. According to [10], the yarn is given three different twists: wrapping twist, twisting twist, and the self-twist of the core yarn and wrapping yarn before the twisting and wrapping courses.

A typical covered yarn consists of core and of two covering components. This yarn is known as multi-component yarn in which one component, the core material, stays nearly at the centre of the yarn while the others cover it [4, 5, 10 – 12].

According to [4, 5, 9, 12] the structure of the yarns with spirally arranged components is rather complex object because various manufacture factors are available. In other words, it is possible to regulate the structure and the mechanical properties of these yarns as well as to determine it by means of these factors [5, 9, 10]. For instance, for these structures, due to the different changes in their core yarns and covering yarns in the tensile course, they have two rupture states, one is core yarn rupture and the other is covering yarn rupture [4, 5, 13].

A coil length of covering component is one among various structural indices of covered yarn. Each covering component has a shape of spiral line in structure of covered yarn [9, 12]. The equations and methodology for predicting the coil length of components spirally arranged in complex structure yarns have been proposed in [14, 15]. The values of coil length of spiral components are necessary in predicting of a portion of consumption of these components, also in calculating of a percentage composition and a total linear density of the covered yarn.

A task of the current study is to simulate relations between the manufacture parameters of covered yarn and the coil length indices of covering components as well as to present a quantitative evaluation of the possibilities of regulation of these indices.

MATERIALS AND METHODS

As the object of this research the theoretical relations between manufacture factors of typical covered yarn usually used in stretch textiles and the coil length of covering components are discussed. This yarn consists of 89.6-tex polyurethane elastomeric multifilament core yarn and of two 13.4 tex viscose (CV) multifilament covering yarns. The average values of overall density in accordance with [4] are the following: 1.10 Mg/m^3 for the core, 1.00 Mg/m^3 for the covering components.

According to [15] the coil length of the first covering yarn depends on the following manufacture parameters: the delivery speed of covered yarn v_d, the rotational speed of first hollow spindle n_{s1}, and the core stretch ratio during wrapping ε_1. The predicting of coil length of the second covering component has analogy with previous

*Corresponding author. Tel.: +370-37-353862; fax:+370-37-353989.
E-mail address: *Donatas.Petrulis@ktu.lt* (D. Petrulis)

calculations. The additional influence of the evenness of intermediate product here takes part too. Therefore in a case of the second covering yarn the following technological parameters are considered: the delivery speed of covered yarn v_d, the rotational speed of both hollow spindles n_{s1} and n_{s2}, and the core stretch ratio during wrapping ε_1.

The values of manufacture parameters were chosen in accordance with the experiment [9, 16, 17]. The following ranges of these parameters, showed below, were used. The delivery speed of covered yarn v_d fluctuated in range 0.05 – 0.65 m/s. The values of rotational speed of the first hollow spindle n_{s1} and of the second spindle n_{s2} varied from 70 to 400 s^{-1}. The variation of the core stretch ratio during wrapping ε_1 equalled 2.0 – 3.2. For the cases of the fixed manufacture parameters the following values were used: $v_d = 0.35$ m/s, $n_{s1} = 240\ s^{-1}$, $n_{s2} = 180\ s^{-1}$, $\varepsilon_1 = 2.6$.

The further study was proposed with a goal to evaluate the intensity of influence of each manufacture factor on a coil length change of covering components. The coil length of the first covering yarn can be described as a function [15]:

$$l_{11} = f(v_d, n_{s1}, \varepsilon_1). \quad (1)$$

The average value of the coil length of the second covering component is [15]:

$$\overline{l_{21}} = \varphi(v_d, n_{s1}, n_{s2}, \varepsilon_1). \quad (2)$$

The partial differences of the functions (1) and (2) for each manufacture factor are the following:

$$\Delta_{v_d} l_{11} = f(v_d + \Delta v_d, n_{s1}, \varepsilon_1) - f(v_d, n_{s1}, \varepsilon_1), \quad (3)$$

$$\Delta_{n_{s1}} l_{11} = f(v_d, n_{s1} + \Delta n_{s1}, \varepsilon_1) - f(v_d, n_{s1}, \varepsilon_1), \quad (4)$$

$$\Delta_{\varepsilon_1} l_{11} = f(v_d, n_{s1}, \varepsilon_1 + \Delta\varepsilon_1) - f(v_d, n_{s1}, \varepsilon_1), \quad (5)$$

$$\Delta_{v_d} \overline{l_{21}} = \varphi(v_d + \Delta v_d, n_{s1}, n_{s2}, \varepsilon_1) - \varphi(v_d, n_{s1}, n_{s2}, \varepsilon_1), \quad (6)$$

$$\Delta_{n_{s1}} \overline{l_{21}} = \varphi(v_d, n_{s1} + \Delta n_{s1}, n_{s2}, \varepsilon_1) - \varphi(v_d, n_{s1}, n_{s2}, \varepsilon_1), \quad (7)$$

$$\Delta_{n_{s2}} \overline{l_{21}} = \varphi(v_d, n_{s1}, n_{s2} + \Delta n_{s2}, \varepsilon_1) - \varphi(v_d, n_{s1}, n_{s2}, \varepsilon_1), \quad (8)$$

$$\Delta_{\varepsilon_1} \overline{l_{21}} = \varphi(v_d, n_{s1}, n_{s2}, \varepsilon_1 + \Delta\varepsilon_1) - \varphi(v_d, n_{s1}, n_{s2}, \varepsilon_1). \quad (9)$$

where Δv_d, Δn_{s1}, Δn_{s2}, $\Delta\varepsilon_1$ are the partial increments of the manufacture factors.

It is important to understand that the direct comparison of these partial differences isn't correct, as the ranges of variation of the manufacture factors are different. For example, the difference between the maximal and minimal values for the factor v_d equals 13 times. Meanwhile, the extreme values differ approximately 5.7 times for the factors n_{s1} and n_{s2}, also only 1.6 times for the factor ε_1. Therefore only the comparable partial differences of the functions (1) and (2) were computed. These differences correspond to 100 % partial increments of the manufacture factors. For instance, the influence of the factor v_d on the coil length difference of the first covering component was evaluated in such form:

$$\Delta_{v_{d100}} l_{11} = \frac{f(v_d + \Delta v_d, n_{s1}, \varepsilon_1) - f(v_d, n_{s1}, \varepsilon_1) \Delta v_d^{100}}{\Delta v_d}, \quad (10)$$

where Δv_d^{100} is a 100 % partial increment of the factor v_d.

In this way the other comparable partial differences were also found. It is worth to note that the coil length indices aren't in linear relation with the manufacture factors. Therefore the above-mentioned partial differences reflect the average influence of each factor in a range of variation.

RESULTS AND DISCUSSIONS

The relations reported in this paper are based upon the use of the mathematical description, which has been proposed for covered yarn model in [15]. To obtain these relations the following equations for coil length of the covering yarns are used:

$$l_{11} = \left\{ 4\pi \left(\sqrt{\frac{T_c}{\delta_c (1 + \varepsilon_1)}} + \sqrt{\frac{T_1}{\delta_1}} \right)^2 + \left(\frac{v_d}{n_{s1}} \right)^2 \right\}^{1/2}, \quad (11)$$

$$\overline{l_{21}} = \left\{ 4\pi \left(\sqrt{\frac{T_c}{\delta_c (1 + \varepsilon_1)}} + \sqrt{\frac{T_2}{\delta_2}} + 2 k_{e1} \sqrt{\frac{T_1}{\delta_1}} \right)^2 + \left(\frac{v_d}{n_{s2}} \right)^2 \right\}^{1/2}, \quad (12)$$

where v_d is a delivery speed of covered yarn, n_{s1}, n_{s2} is a rotational speed of both spindles, ε_1 is a core stretch ratio during wrapping, T_c, T_1, T_2 is a linear density of core and both covering yarns, δ_c, δ_1, δ_2 is an overall density of core and both covering yarns, k_{e1} is a coefficient of evenness of intermediate product.

The coefficient k_{e1} is defined as:

$$k_{e1} = \frac{2\, n_{s1}}{v_d} \sqrt{\frac{T_1}{\pi \delta_1}}. \quad (13)$$

Therefore, we finally have:

$$\overline{l_{21}} = \left\{ 4\pi \left(\sqrt{\frac{T_c}{\delta_c (1 + \varepsilon_1)}} + \sqrt{\frac{T_2}{\delta_2}} + \frac{4 n_{s1} T_1}{\sqrt{\pi}\, v_d \delta_1} \right)^2 + \left(\frac{v_d}{n_{s2}} \right)^2 \right\}^{1/2}. \quad (14)$$

Fig. 1 shows the influence of delivery speed of covered yarn on the coil length of the first and the second covering yarn. The coil length increases as delivery speed raises. An intensity of increase of the coil length grows in a range of higher delivery speed. For instance, the increase of the coil length of the first component in a range of delivery speeds 0.05 – 0.25 m/s equals 0.44 mm. While, if delivery speed raises from 0.45 m/s to 0.65 m/s, this coil length increases even in 0.77 mm. Moreover, the coil length of the second component exceeds the coil length of the first component because rotational speed of the second hollow spindle is less if compared with the first hollow spindle. It is worth to note that an influence of a factor of increased distance between axis of covered yarn and axial line for second covering yarn here takes part too. Also the evenness of intermediate product influences on coil length of the second covering yarn.

Another situation was determined for factor of rotational speed of hollow spindles n_{s1} and n_{s2} (see Fig. 2 and Fig. 3). Firstly, the coil length of the first and the second component falls if rotational speed of corresponding spindle raises. Secondly, the above mentioned fall is of less intensity in a range of high speed. Thirdly, the coil length

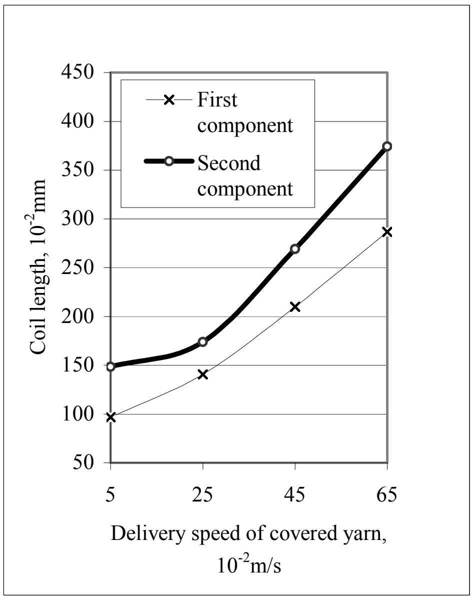

Fig. 1. Influence of delivery speed of covered yarn on coil length of covering components

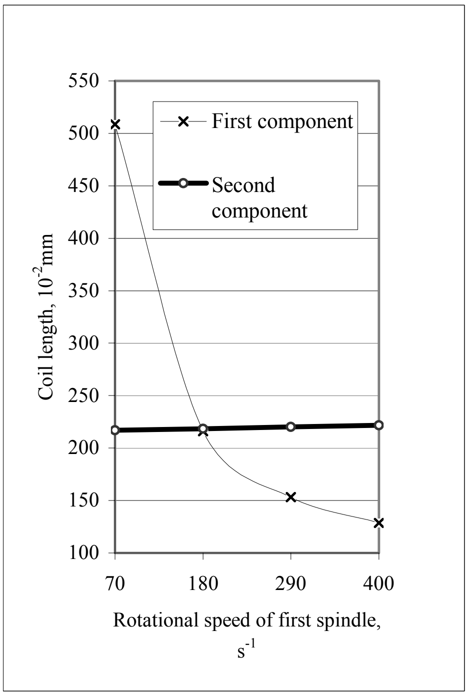

Fig. 2. Influence of rotational speed of first spindle on coil length of covering components

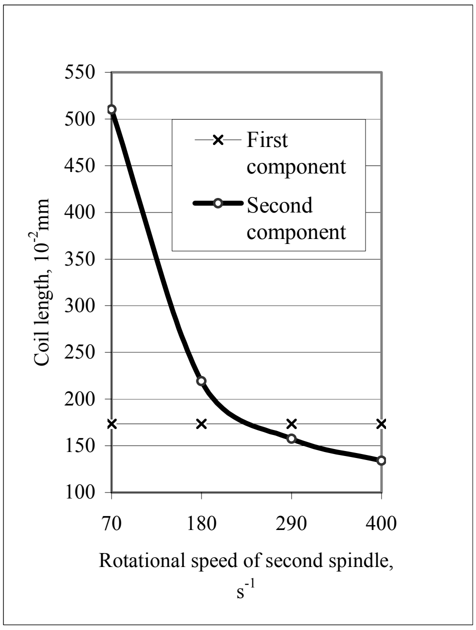

Fig. 3. Influence of rotational speed of second spindle on coil length of covering components

of the another component, as can be seen in Fig. 2 and Fig. 3, remains in fixed level. The proposals made in [15] note that the coil length of the second component depends on rotational speed of the first hollow spindle too. This phenomenon is based on influence of evenness of intermediate product after the first covering component wraps the core. However, this influence, as can be seen in Fig. 2, is very small for the conditions of the current research.

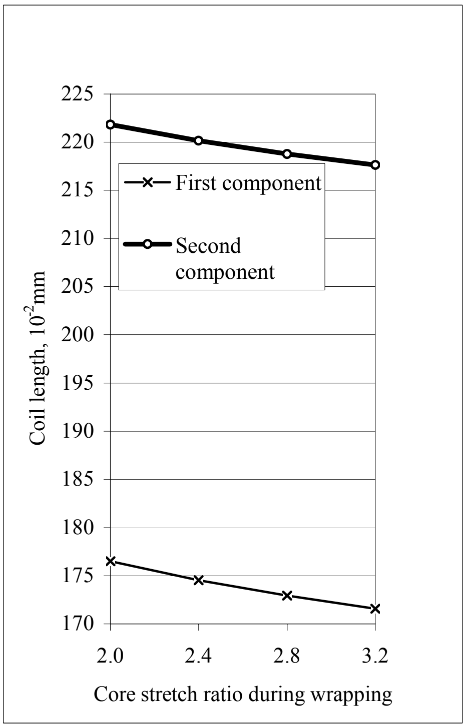

Fig. 4. Influence of core stretch ratio during wrapping on coil length of covering components

One additional factor, the influence of which on the coil length was analysed, is the core stretch ratio during wrapping. The effect of this factor is shown in Fig. 4. After the core is stretched, a perimeter of cross-section of a core or a perimeter of cross-section of a core covered with the first covering component is less in compare with corresponding initial data fixed at zero stretch ratio. Therefore the coil length of the first and the second covering components falls as the core stretch ratio during wrapping increases. A drop of the coil length at the inspected range of ε_1 is rather even but the more intensive drop was computed at the beginning of this range.

The paper is focused on the peculiarities of the theoretical relations. Therefore an issue of a special experimental verification was left beyond the task of the current study. At the same time we can expect rather good agreement between the proposed theory and experimental data. The experiments, presented for similar polyurethane-CV covered yarns in [9], showed rather good correspondence with theory in predicting the indices of coil length of covering components [15]: the deviation varied between –5.2 % and +6.0 %.

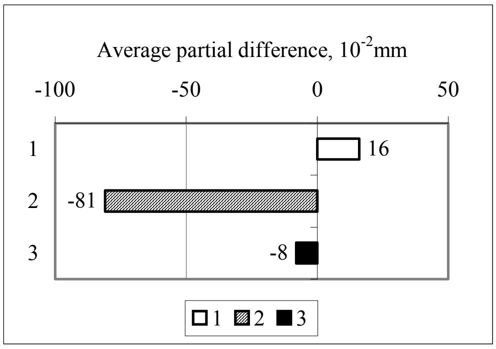

Fig. 5. Average partial differences of coil length of first covering component in respect of 100 % partial increment of: $1 - v_d$, $2 - n_{s1}$, $3 - \varepsilon_1$

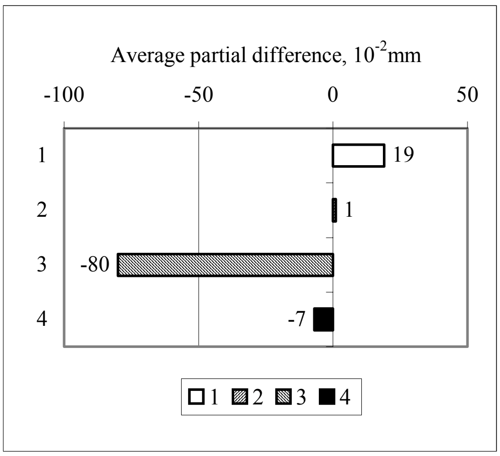

Fig. 6. Average partial differences of coil length of second covering component in respect of 100 % partial increment of: $1 - v_d$, $2 - n_{s1}$, $3 - n_{s2}$, $4 - \varepsilon_1$

The further investigation was carried out with a purpose to evaluate the intensity of the influence of each manufacture factor. The results of average partial differences of the coil length are shown in Fig. 5 and Fig. 6. Positive sign of partial difference means that with increase of manufacture factor a value of coil length increases as well. Such result was obtained for factor v_d (see Fig. 5 and Fig. 6), also for factor n_{s1} (Fig. 6). In the rest cases of the research the negative partial differences were computed. These negative differences show the inverse influence of the factors n_{s1}, ε_1 (Fig. 5), n_{s2}, ε_1 (Fig. 6) on the coil length. In a case of investigation of the partial differences (3) – (5) the manufacture factors are arranged by strength of influence in such order: n_{s1} (maximal influence), v_d, ε_1 minimal influence). For a case of the partial differences (6) – (9) the following arrangement of the factors was estimated: n_{s2} (maximal influence), v_d, ε_1, n_{s1} (minimal influence). Thus, in the investigated range of variation of manufacture factors the coil length of each covering component depends mostly on the rotational speed of appropriate hollow spindle. The influence of delivery speed variation of covered yarn on the coil length is approximately from 4 to 5 times less. The least influence was obtained for factor of core stretch ratio during wrapping, i.e., the effect is from 10 to 11 times less in compare with the strongest influence.

CONCLUSIONS

The theoretical relations between delivery speed of polyurethane – viscose covered yarn, the rotational speed of both hollow spindles, and the core stretch ratio during wrapping on the one hand, and the coil length indices of covering components on the other hand, were computed and analysed.

The coil length increases as delivery speed of the covered yarn raises. Contrary to the influence of the above-mentioned factor the increase of the rotational speed of the spindle decreases the corresponding index of the coil length. The indices of the coil length also fall with the increase of the core stretch ratio during wrapping.

The possibility to use the comparable partial differences of the functions was also suggested.

The most effective opportunity to adjust the coil length was obtained in a case of variation of the appropriate rotational speed of the first and the second hollow spindles. The least influence on coil length was estimated for core stretch ratio during wrapping. This influence is from 10 to 11 times less in compare with the effect of the rotational speed of both spindles.

REFERENCES

1. **Anužis, A., Mackevičienė, J.** New Acetate Yarns, *Lengvosios pramonės technologijos ir dizainas* (*Technologies of Light Industry and Design*), Material of Conference Reports, Kaunas, Technologija, 1997: pp. 286 – 290 (in Lithuanian).
2. **Paulavičiūtė, V., Sadeikienė, D.** Manufacture and Investigation of the Properties of Mixed Yarns Containing Elastane Component, *Vartojimo reikmenų technologijos ir dizainas* (*Technologies and Design of Consuming Materials*), Material of Conference Reports, Kaunas, Technologija, 1999: pp. 267 –271 (in Lithuanian).

3. **Ragaišienė, A.**, **Petrulytė, S.**, **Petrulis, D.** Combination Elastomeric Yarns: Assortment, Use, Analysis of Their Characteristics, *Materials Science* (*Medžiagotyra*) 3 (10) 1999: pp. 58 – 62.
4. **Matukonis, A.**, **Palaima, J.**, **Vitkauskas, A.** Tekstilės medžiagotyra (Textile Materials Science). Vilnius, Mokslas, 1976 (in Lithuanian).
5. **Matukonis, A. V.** Production, Properties, and Use of Union Yarns. Moscow, Legkaya industriya, 1987 (in Russian).
6. **Osman Babaarslan.** Method of Producing a Polyester/Viscose Core-Spun Yarn Containing Spandex Using a Modified Ring Spinning Frame *Text. Res. J.* 71 4 2001: pp. 367 – 371.
7. **Rupp, J.**, **Bohringer, A.** Yarns and Fabrics Containing Elastane *Int. Text. Bull.* 1 1999: pp. 10 –30.
8. **Weber, W.** Spinning Core Yarns Containing Elastane on Customised Ring Spinning Frames *Melliand Textilber.* 74 1993: p. 351 (in German).
9. **Tvarijonavičienė, B. J.** Study on Structure and Mechanical Properties of Polyurethane Elastomeric Covered Yarns *Dr. Sc. Thesis*, Kaunas Polytechnical Institute, Kaunas: 1972 (in Russian).
10. **Xin Li**, **Jianchun Zhang**, **Jiexin Li.** Differential-Twist Wrapped Yarns Made on a Hollow Spindle Spinning Machine *Text. Res. J.* 72 2 2002: pp. 181 – 185.
11. **Xie, Y.**, **Oxenham, W.**, **Grosberg, P.** A Study of the Strength of Wrapped Yarns, Part I: The Theoretical Model *J. Text. Inst.* 77 1986: pp. 295 –304.
12. **Dent, R. W.** The Retraction and Stretch of Wrapped Elastomeric-fibre Core Yarns *J. Text. Inst.* 61 1970: pp. 578 – 587.
13. **Behery, H. M.**, **Nunes, M. F.** The Structure, Tensile Properties, and Morphology of Failure of Wrapped Yarns *J. Text. Inst.* 77 1986: pp. 386 – 402.
14. **Petrulis, D. K.** Calculation of Wrapping Components Winding Length in the Covered Yarns *Technologiya Tekstilnoj Promyshlennosti (Techn. Text. Industr.)* 1 1994: pp. 32 – 39 (in Russian).
15. **Petrulis, D.**, **Petrulytė, S.** Predicting of Coil Length of Components Spirally Arranged in Complex Structure Yarns, *Materials Science* (*Medžiagotyra*) 9 (2) 2003: pp. 224 – 227.
16. **Usenko, V. A.** Silk Twisting. Moscow, Legkaya i Pishchevaya Promyshlennost, 1983 (in Russian).
17. **Johnson, R. H.** ITMA'99: A Review *Text. Progr.* 1 – 2 2000: pp. 13 – 21.