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Comparative Analysis of Fancy Yarns Produced on a Ring Twisting System

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Abstract
In this article, the shape coefficient of yarn was used as a tool for classifying fancy yarns. On the basis of experiments conducted in this research, characteristic values of the shape coefficient for different yarn structures have been established. The same research material and twist were used in the experiments. Changes were made to preliminary tensions of component yarns in the twist zone and to the overfeed of the effect yarn. The fancy yarns analysed were compared in terms of their ability to carry tensile stresses. It was demonstrated that spiral yarn had the best strength parameters of the group of yarns under analysis, while the strength of loop yarn, which is produced in a two-stage process of twisting three identical component yarns, is even lower than that of a single yarn. The results of the experiments conducted by the author have specific practical implications for the industry and for the process of designing and producing fancy yarns.

Key words: *fancy yarns, shape coefficient, strength, elongation.*

Introduction - identification of research problem

Research work relating to fancy yarns conducted at the Faculty of Material Technologies and Textile Design has been presented in a paper by T. Jackowski [1]. The yarn structure analyses performed by L. van Langehnove [2 - 4] provided a theoretical basis for the studies conducted. A yarn shape coefficient was introduced as a new parameter characterising fancy yarns [5]. The shape coefficient of fancy yarn is defined as a quotient of the outer diameter of the edge of the helix line formed by the core yarn in a multiplied yarn subjected to preliminary tension, and of the outer edge diameter of the helix line formed by the effect yarn in a multiplied yarn subjected to preliminary tension.

$$K = \frac{D_{Rs0}}{D_{Es0}} \qquad (1)$$

where:
K - shape coefficient of fancy yarns
D_{Rs0} - diameter of the helix line formed by the external edge of the core yarn in a multiplied yarn under a preliminary load,
D_{Es0} - diameter of the helix line formed by the external edge of the effect yarn in a multiplied yarn under a preliminary load.

The shape coefficient of fancy yarn is a function of the fancy yarn overfeed, as evidenced by loop yarn, for example:

For a loop yarn composed of identical component yarns, the value of the shape coefficient of the fancy yarn amounts to:

$$K = \frac{2d}{2d + a} = \frac{1}{1 + \frac{a}{2d}} \qquad (2)$$

where:
d – diameter of a single component yarn in mm,
a – length of amplitude of the sinusoidal line created by loops in mm (“a” depends on the overfeed of the effect yarn).

An objective parameter for classifying fancy yarns according to their structural complexity has not as yet been introduced [6]. The methods of classifying fancy yarns that have been used up to now have a subjective character and function on the basisof adjectives introduced by producers to describe the shape of fancy yarns (for example: loop yarn, bunch yarn, snarls yarn).

Scientific thesis

1. The shape coefficient is an objective parameter characterising the structure of fancy yarns.
2. The shape coefficient determines the strength properties of yarns.

Research material

In a twisting machine producing fancy yarns, there are two essential machine settings that make it possible to control the structure of fancy yarns: the yarn twist and overfeed of the effect yarn in relation to the core yarn. The overfeed is obtained from the difference between the speed of delivering the core yarn and that of delivering the effect yarn. By controlling the speed of delivering component yarns into the twist zone, we control tensions generated in component yarns. An analysis of the influence of yarn twist on the structure and strength of fancy yarns was carried out during the process of verifying the viability of strength models for fancy yarns [1]. A cycle of experiments was conducted to provide evidence that the overfeed of the effect yarn has an impact on the production of different structures of fancy yarn.

Constant machine twist was used (237TPM, direction Z). All studies were performed on the same research material, which was also the same as the one used in verifying the strength models of fancy yarns [1]. Standard polyacrilonitril yarn with a twist of 460TPM, direction Z, and linear density of 25.1tex was used as a single component yarn. The overfeed of the effect yarn was manipulated to change the structure of the fancy yarn. The fancy yarns under analysis were produced on a ring twisting machine type PL 31C. Spiral yarn and wrapped yarn were obtained by using the same twist direction as that of the single component yarn (Z). Loop yarn was produced in two stages: In the first loops were produced from the effect yarn on the core yarn, with a twist consistent with the twist direction of the component yarns (Z); in the second stage, which involved the fastening of loops with a binding yarn, twist (S) was used to enhance the loops. It is a traditional method of producing loop yarn on an industrial ring twisting machine. All tests of yarn properties were carried out in accordance with European standards. The tests were repeated 50 times for each parameter estimate. ***Tables 1, 2*** and ***3*** present the computed average values of parameter estimates.

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Test results

Spiral (mouliné) yarn

Due to the use of identical component yarns and preliminary tension conditions in the twist zone, which were the same for each yarn (with 0% overfeed of the effect yarn in relation to the core yarn), the process of twisting three component yarns resulted in the formation of a spiral (mouliné) yarn. The shape coefficient calculated on the basis of equation 1 equals one $K = 1$, which is characteristic for this type of yarn. Such a value of the shape coefficient of fancy yarn corresponds to a yarn in which all three component yarns carry the same tensile stresses. All component yarns are in constant contact with one another along the entire length of the spiral yarn. Due to the zero overfeed and the shape coefficient being equal to one, spiral yarn is a basic form of fancy yarn and provides a starting point for further analysis of the structure of fancy yarns in the function of increasing the overfeed of the effect yarn.

The characteristic feature of spiral (mouliné) yarn is that all component yarns are parallel to one another. In relation to the longitudinal axis of spiral yarn, the component yarns are positioned at an angle whose tangent is a function of the twist and diameter of the spiral yarn. In spiral yarn, the effect, core and binding yarns are indistinguishable because all component yarns perform the same function in fancy yarn. A comparative analysis was undertaken to establish the strength parameters of two- and three-component spiral yarns, comparing them with the corresponding parameters of a single yarn (***Table 1***). The structure of three-component spiral (mouline) yarn produced under preliminary tension is presented in ***Figure 1***.

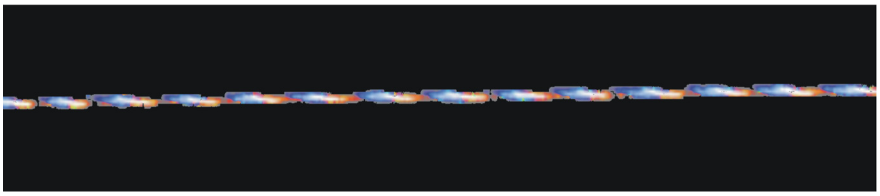

***Figure 1**. Three-component spiral (mouline) yarn under preliminary tension (Own research).*

***Table 1.** Results of the process of static stretching two- and three-component spiral yarns compared with corresponding parameters of a single yarn.*

Kind of yarn	Linear density, tex	Twist, TPM	Breaking force, N	Strength, N/tex
Three-component spiral yarn	79.6	237 Z	12.63	0.158
Two-component spiral yarn	52.1	237 Z	7.43	0.142
Single yarn	25.1	460 Z	3.47	0.138

In the case of three-component yarn, the linear density of the spiral yarn was found to have increased over three times (79.6 tex) in comparison with that of the single yarn (25.1 tex). This, a more than three-fold increase in the linear density of the spiral yarn compared to that of the one-component yarn, was caused by the shrinkage of single component yarns as a result of their twisting into the form of a spiral yarn.

The force breaking the spiral yarn was found to have increased over three times (12.63 N) in comparison with that breaking the single yarn (3.48 N). There was a significant increase (by 44%) in the strength of the three-component spiral yarn (0.16 N/tex) in comparison with that of the single yarn (0.14 N/tex).

The linear density and force breaking the two-component yarn were found to have doubled (52.1 tex; 7.44 N) in comparison with the linear density and breaking force of the single yarn (25.1 tex; 3.48 N). It was also found that there had not been any significant increase in the strength of the two-component spiral yarn (0.14 N/tex) in comparison with that of the single yarn (0.139 N/tex).

Changes in the stretching force versus the elongation of the three-component, two-component and single yarns were analysed to identify characteristic features of the yarn stretching process (***Figures 2, 3** & **4***).

In all three diagrams there is only one peak, which proves that all component yarns broke simultaneously. In the case of the single yarn, the diagram of the relationship between the elongation and the force stretching the yarn clearly shows that staple fibres slide apart during the process of yarn stretching, which is visible in the irregular shape of the step diagram, especially in the part relating to the plastic and permanent strain. One can

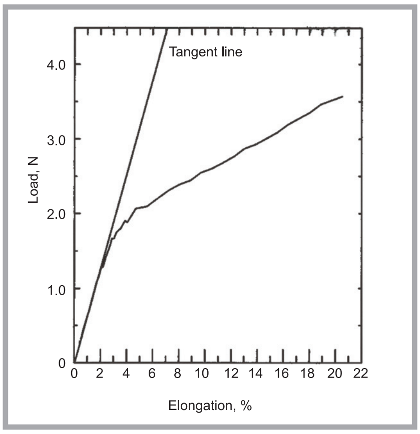

***Figure 2.** Diagram showing the relationship between tensile force and elongation for a single yarn. (Own research).*

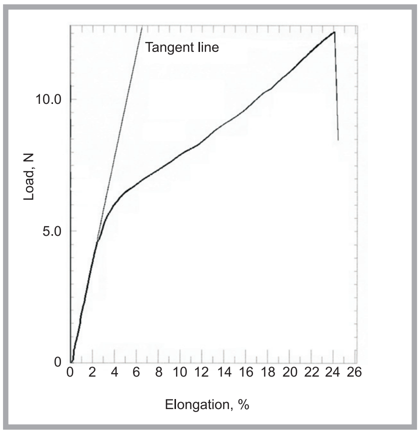

***Figure 3.** Diagram showing the relationship between tensile force and elongation for two-component spiral (mouliné) yarn. (Own research).*

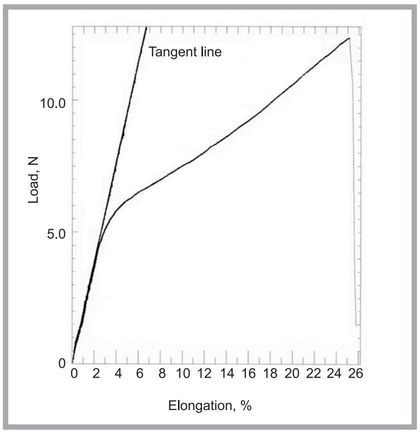

***Figure 4.** Diagram showing the relationship between tensile force and elongation for three-component spiral (mouliné) yarn. (Own research).*

observe that the elongation increases momentarily, while the value of the tensile force (horizontal lines) remains the same, or even decreases for a moment when the elongation is very small (rupture of fibres). In the case of the two-component yarn, one can notice that the tensile force is already increasing more steadily in the function of elongation.

In the destruction of the two-component yarn, phenomena associated with the change in the structure of the entire multiplied yarn prevail over the phenomena that occur at the level of a single yarn. In the case of the three-component yarn, the diagram progresses even more steadily, the shape of which resembling the progression of the stretching process of a twisted multifilament yarn, i.e. the destruction of this yarn is determined by the phenomena that take place in the entire structure of the multiplied yarn. In addition, the breaking tendency of staple fibres in the single yarn increased, while their tendency to slide apart decreased. Such phenomena can be explained by mutual lateral pressures exerted by component yarns and by the increase in the surface of mutual contact between them.

Wrapped yarn

Wrapped yarn was created using non-zero overfeed of the effect yarn in relation to the core yarn. In comparison with the overfeed characteristic for the spiral yarn, the overfeed in the wrapped yarn increased by 8%. Wrapped yarn is characterised by a straightened structure of the core yarn and the effect yarns wrapped around the core yarn so as to ensure their full contact with the core yarn along the entire length of the wrapped yarn. The value of the shape coefficient for wrapped yarn, calculated with equation 1, amounts to $K = d_{R0}/D_{Es0}$ (for wrapped yarn in full contact with the effect and core yarns $D_{sR0} = d_{R0}$). For two-component yarn composed of identical yarns, $K = 0.75$, and for three-component yarn - $K = 0.5$. In the case of wrapped yarn, tensile stresses are predominantly carried by the core yarn and, to a lesser extent, by the wrapping yarns. However, due to the close contact between the core yarn and wrapping yarns, staple fibres become strongly locked in the core yarn. As a result, the core yarn can carry higher tensile stresses than the single component yarn. Despite the fact that wrapping yarns do not carry tensile stresses to a considerable extent, they nonetheless have a significant effect on increasing the value of tensile stresses that can be carried by the wrapped yarn,

Figure 5. *Two-component wrapped fancy yarn (photo taken as the yarn was being produced on a ring twisting machine, in the zone between the twisting cone and the guide positioned just over the spindle. Own research).*

Table 2. *Results of the process of the static stretching of two- and three-component spiral and two- and three-component wrapped yarns as compared with corresponding parameters of a single yarn.*

Kind of yarn	Linear density, tex	Twist, TPM	Max. breaking force, N	Strength, N/tex
Three-component wrapped yarn	87.8	237 Z	9.22	0.105
Three-component spiral yarn	79.6	237 Z	12.63	0.158
Two-component wrapped yarn	52. 6	237 Z	5.39	0.102
Two-component spiral yarn	52.1	237 Z	7.43	0.142
Single yarn	25. 1	460 Z	3.47	0.138

because wrapping yarns generate lateral compressive stresses, which ensures the better locking of staple fibres in this yarn. The structure of two-component wrapped yarn produced under preliminary tension is presented in ***Figure 5***. In the wrapped yarn one can clearly distinguish the core yarn and the wrapping yarn.

A comparative analysis was carried out to examine the strength parameters of two- and three-component wrapping yarns and compare them with the same parameters established for two- and three-component spiral yarns and single component yarn (***Table 2***).

The linear density of the three-component wrapped yarn was found to have increased by about 10% (87.8 tex) in comparison with that of the three-component spiral yarn (79.6 tex), and by about 3.5 times (87.8 tex) in comparison with the single yarn (25.1 tex). In the case of wrapped yarn, this is due to the fact that wrapping yarns are delivered at a higher rate than the core yarn, as compared to three-component spiral yarn, in which all the three yarns are delivered into the twist zone at the same speed. For the two-component wrapped yarn (52.6 tex), the linear density did not increase significantly in comparison with the two-component spiral yarn (52.1 tex). There was, however, a more than two-fold increase in the linear density of the two-component wrapped yarn (52.6 tex) in comparison with that of the single yarn (25.1 tex).

It was found that the force breaking the three- and two-component wrapped yarns had become significantly reduced (9.22 N and 5.39 N, respectively) in comparison with that breaking the three-component (12.63 N) and two-component spiral yarns (7.43 N), which is connected with the progression of the destruction process of the wrapped yarn, in which the core yarn is the first to break, followed by the wrapping yarns. In the case of the spi-

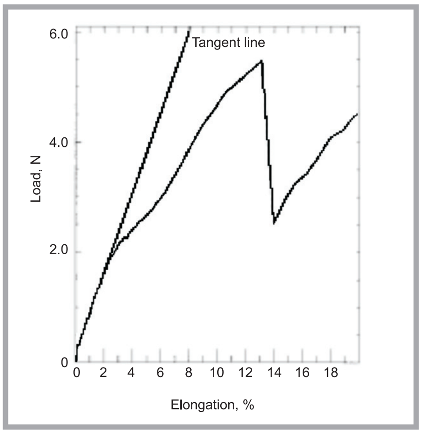

Figure 6. *Diagram showing the relationship between the tensile force and elongation for two-component wrapped yarn. (Own research).*

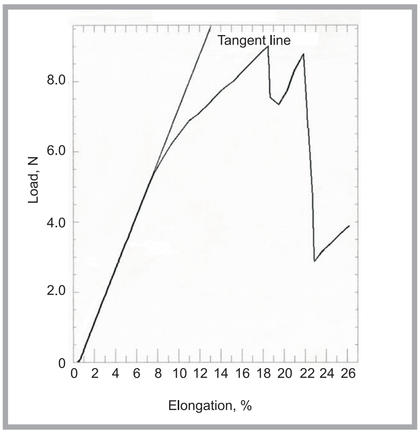

Figure 7. *Diagram showing the relationship between the tensile force and elongation for three-component wrapped yarn. (Own research).*

ral yarn, tensile stresses were at all times evenly carried by all component yarns, which ultimately broke at the same time. In the group of yarns under analysis, the highest breaking force was carried by the three-component spiral yarn (12.63 N). The spiral structure characterised by shape coefficient $K = 1$ is especially recommended when high tensile stresses are carried.

The strength of the wrapped yarn (three-component yarn: 0.105 N/tex; two-component yarn: 0.102 N/tex) is lower than the strength of the spiral yarn (three-component yarn: 0.16 N/tex; two-component yarn: 0.14 N/tex), which is connected with the fact that the main stresses in the wrapped yarn are mostly carried by the core yarn. In addition, the strength of the wrapped yarn is lower (or comparable) than that of he single yarn (0.138 N/tex). This is associated with a significant increase in the linear density of the wrapped yarn caused by the overfeed of wrapping yarns, which do not carry any significant tensile stresses. The strength of two- (0.102 N/tex) and three-component wrapped (0.105 N/tex) yarns are comparable.

An analysis was carried out to examine tensile forces acting on wrapped yarns as a function of the elongation. Its findings are presented in diagrams (***Figures 6*** & *7*).

As follows from the analysis of these diagrams, the destruction of wrapped yarn involves the simultaneous rupture of all component yarns. The curve of the diagram for the two-component wrapped yarn progresses similarly to the relevant function for single yarns, with clearly visible sliding or rupture of particular staple fibres, demonstrating the minimal effect of lateral pressures exerted by wrapped yarn on the core yarn (i.e. for this structure of fancy yarn, it is not the minimum borderline value of the twist that allows staple fibres to become sufficiently locked in component yarns). On the other hand, the progression of the diagram for the three-component yarn indicates that in the section in which tensile stresses are carried mainly by the core yarn, lateral stresses exerted by the wrapping yarn on the core yarn do have a significant effect, as evidenced by the progression of this function along this section, which is smoother than in the corresponding section of the function for the two-component wrapped yarn.

If we want to increase the force breaking the wrapped yarn, we should increase the number of core yarns because tensile stresses are mostly carried by them. However, the size of the plane of mutual contact between the core yarn and wrapping yarns is an important parameter too. The larger the area of mutual contact between the component yarns, the easier it is to lock particular fibres in the yarn so as to avoid the phenomenon of their mutual sliding, thus increasing the ability of the wrapped yarn to carry higher tensile stresses.

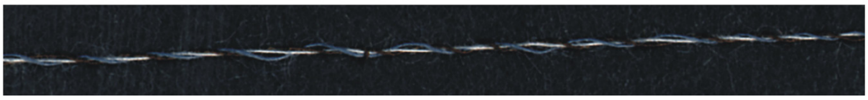

Figure 8. *Frotté yarn under preliminary tension. (Own research).*

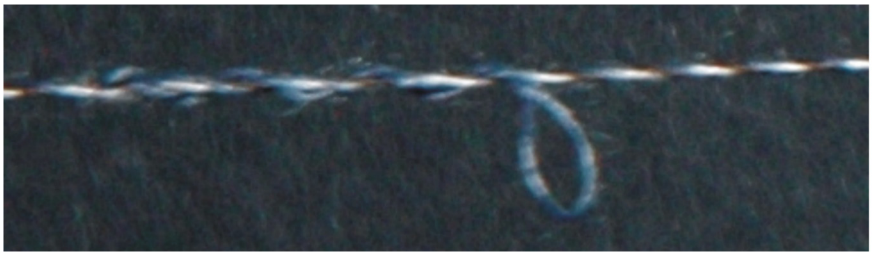

Figure 9. *Three-component loop yarn with a bouclé effect. (Own research).*

Loop frotté yarn with a sinusoidal effect

A frotté yarn with a sinusoidal effect was produced by increasing the overfeed by 6% in comparison with the wrapped yarn. In the production of frotté yarn with a sinusoidal effect, the overfeed used amounted to 14%, which is the smallest overfeed of the effect yarn that makes it possible (in such experimental conditions) to break the continuity of contact between the effect yarn and core yarn. There must be at least three component yarns to obtain a loop yarn. Loop yarns are often characterised by a multi-thread structure, in which one can distinguish three basic components:

- the core component – a yarn delivered with the highest tension during the twisting process and with zero overfeed,
- the wrapping component – a yarn delivered with the smallest tension during the twisting process and with non-zero overfeed,
- the binding component – a yarn that is needed to fasten the effects on the fancy yarn.

Figure 8 presents a loop frotté yarn under preliminary tension, and after tensions have been relaxed. One can notice the waviness of the core yarn and the sinusoidal form of the loop, where the form of the loop yarn corresponds to shape coefficient K < D_{Rs0}/D_{Es0}<0.5. Tensile stresses are mostly carried by the core yarn and binding yarn.

Loop yarn with a bouclé effect and a snarl yarn

The loop yarn presented below was produced by twisting together three identical polyacrilonitril yarns on a ring twisting machine type PL-31C. It was possible to carry out this process by manipulating the tensions of component yarns as they were being delivered into the twist zone and the angle at which they were introduced into the twisting cone. A 50% overfeed of the effect yarn was used, which is the smallest overfeed of the effect yarn (for the experimental conditions) that makes it possible to produce a loop yarn with a bouclé structure – the effect yarn forms a clear closed loop. In the loop yarn one can distinguish the core yarn (white), binding yarn (brown) and effect yarn (blue). The main tensile stresses are carried by the core and binding yarns. ***Figure 9*** presents three-component loop yarn under preliminary tension.

By controlling the tensions of particular component yarns in the guide zone and by considerably increasing the amount of overfeed of the effect yarn, a snarl yarn was obtained (***Figure 10,*** see page 40). A snarl yarn constitutes a borderline form of a loop yarn. If the overfeed of the effect yarn is increased any further, snarls become locally twisted, which means that a fancy yarn with point effects is obtained – bunch yarn.

Table 3 (see page 40) compares the strength parameters of the three-component yarns: spiral, wrapped and loop yarns, and the single yarn.

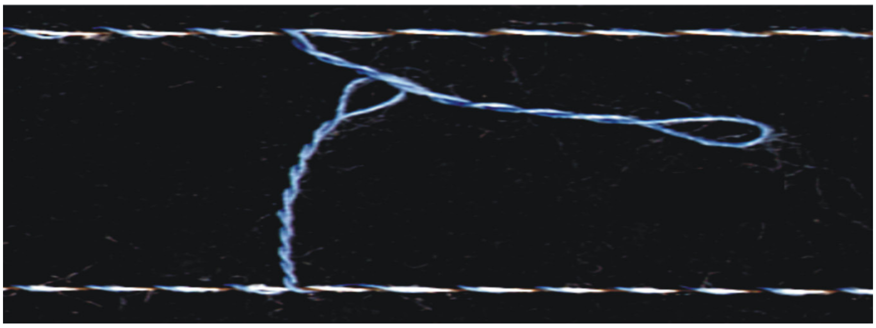

Figure 10. Snarl yarn produced on the basis of bouclé loop yarn, in a one-stage twisting process on a ring twisting machine. (Own research).

Table 3. Comparison of the strength parameters of the three-component yarns under analysis: spiral, wrapped and loop yarns and the single yarn.

Kind of yarn	Linear density, tex	Twist, turns/M	Max. breaking force, N	Strength, N/tex
Three-component wrapped yarn:	87.8	237 Z	9.221	0.1050
Three-component spiral yarn	79.6	237 Z	12.63	0.1586
Three-component loop yarn:	119.1	233 Z/S	6.7	0.0560
Single yarn	25.1	460.4 Z	3.479	0.1386

An analysis of the diagram of the stretching of the loop yarn versus elongation was carried out. ***Figure 11*** presents changes in the force stretching the loop yarn in the function of elongation.

It was found that in the group of three-component yarns, the loop yarn is characterised by:
- The largest linear density - due to a very large overfeed of the effect yarn. It is the most material-intensive yarn in the group of yarns under analysis.
- The lowest breaking force (6.7 N); this was due to the fact that, as is the case for a loop yarn, tensile stresses are carried by the binding and core yarns. The binding yarn is the first to break, which is twisted in the second stage of production of the loop yarn, in the so-called countertwist to the basic twist of the binding yarn, i.e.: the binding yarn is characterised by twist Z and is twisted with the loop yarn (in order to fasten the loops) in direction S. As a result, staple fibres become untwisted in the binding yarn, weakening the stress-carrying properties of this yarn. When designing a loop yarn, it is essential to choose a binding yarn of high tenacity.
- The lowest strength (0.056 N/tex). The strength of a loop yarn is over two times lower than even that of a single yarn (0.14 N/tex), which is due to the fact that the linear density of a loop yarn is very large, while the value of the breaking force is low (depending on the properties of the binding yarn).
- The destruction of a loop yarn is determined by the following factors, ranked according to their significance and the order in which raptures occur:
  - binding yarn.
  - core yarn
  - effect yarn – it breaks due to the sliding of fibres, which is caused by incomplete contact with other yarns and the weakening of the effect yarn as a result of its twisting with the binding yarn in the so-called countertwist, i.e. the effect yarn, characterised by basic Z twist, was twisted with the binding yarn in direction S – staple fibres became untwisted in the effect yarn.

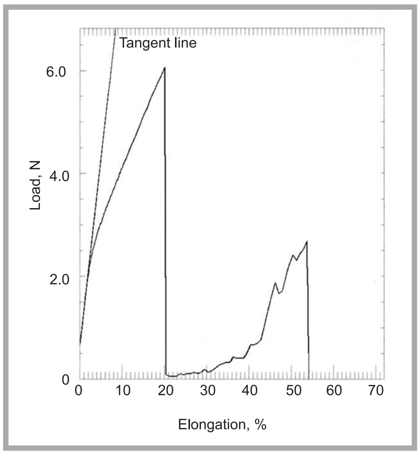

Figure 11. Diagram of changes in the force stretching the loop yarn in the function of elongation. (Own research).

The use of countertwist in the two-stage process of twisting loop yarn with binding yarn weakens the loop yarn.

Conclusions

1. The shape coefficient determines the strength of yarns. As the shape coefficient decreases, the value of tensile stresses that can be carried by this yarn decreases too. Spiral yarn can carry the highest tensile forces (K = 1), while the lowest are carried by loop yarn (K < 0.5).

2. Loop yarn produced on a ring twisting machine in a two-stage process of twisting three identical component yarns could be characterised by even lower strength than a single component yarn (in the case of the retwisting process with binding yarn conducted in the opposite direction to the first process of twisting core yarn and effect yarn in the form of loops).

3. The destruction of loop yarn is determined by the binding yarn. In the process of designing loop yarn, one should choose a binding yarn that can carry high tensile forces.

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