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Research of influence of blended yarn structure including stainless steel fibers on its properties

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Abstract: Analysis of changes in the electrical resistance of different blended of yarns containing stainless steel fibers Bekinox® before and after plying very important for develop antistatic textile materials. Hypothesis was suggested that the plying of two strands leads to yarn conductivity increasing because of rise of the contacts number between stainless steel fibers on their surfaces. Producing of ring-spun 20 tex yarns and 2-ply yarns of linear density 20 tex × 2 were investigated. It is found that that the addition of 10 % stainless fibers into the yarn reduces its electrical resistance in 105 – 106 times. Experimental results show that after plying the yarn conductivity increases. However, this degree of this effect depends on the type of non-conductive fiber (cotton or polyester). Based on the yarn structure simulation it is proven that plying of two strands leads to yarn conductivity increasing because of rise of the contacts number between stainless steel fibers on their surfaces.

1. Introduction

At present development of textiles for special application with antistatic and shielding properties is relevant task due to the fact that the problem of electrostatic safety ensuring becomes increasingly important not only at industrial but also at domestic facilities as well as for everyday clothes [1, 2].

Today, the range of electrically conductive fibers is very wide, companies around the world are engaged in their development and production. These are monocrystalline and polycrystalline metal fibers, various types of glass and ceramic fibers, carbon fibers, synthetic fibers metallized in various ways [3, 4].

The objective of the research is to assess the influence of the structure of blended yarns included stainless steel fibers Bekinox® on their properties. Bekaert offers Bekinox® fibers and yarns for antistatic textiles [5]. Bekinox® dissipates any electrostatic charges generated, to ensure the safety of the grounded wearer or user. Hypothesis was suggested that the plying of two strands leads to yarn conductivity increasing because of rise of the contacts number between stainless steel fibers on their surfaces.

2. Method used

The investigations were carried out theoretically using simulation methods and experimentally in the cotton spinning mill Gronitex (Belarus). To produce yarn containing electrically conductive fibers the sliver of Bekinox® fibers was blended with cotton and polyester slivers at draw frame SB-D-40 (Rieter). The sliver of Bekinox® fibers had the following characteristics:

- linear density of sliver– 4000 tex;
- nominal length of fiber – 47 mm;
- linear density of fiber – 0,9 tex.

During the experimental studies, the samples of ring-spun 20 tex yarns and 2-ply yarns of linear density 20 tex × 2 of the following blends were produced:

1) cotton – 90 %; Bekinox® VS – 10 %.
2) polyester – 90 %; Bekinox® VS – 10 %.

The cotton/ Bekinox® blended sliver manufacturing was as follows. At the first stage the combed sliver from cotton Pima was produced using conventional technology. After combing the cotton sliver was processed at one draw frame stage in order to eliminate periodic unevenness. Then 7 cotton slivers of linear density 4800 tex and 1 Bekinox® sliver were folded on draw frame RSB D-40. Thus, the percentage of the conductive fibers in the blended sliver was calculated to be 10,6 %. Polyester/ Bekinox® blended sliver was produced without combing process.

Spinning machine G35 (Rieter) used for ring-spun yarn manufacturing. For yarn plying used twisting machine Geminis S 261 B / BF (Savio). The optimal settings of draw frame, spinning and twisting machines were determined during experimental studies.

The properties of the investigated yarn are significantly affected by the content of electrically conductive fibers and their variation in the yarn cross sections, as well as the yarn evenness. To a great extent, these characteristics are determined by the properties of the blended sliver. Because of the electrically conductive fibers presence in the slivers it was impossible to use capacitive sensors to determine unevenness since the method used allows testing only dielectric materials.

In this regard, the percentage of Bekinox® fibers in the blends with cotton was determined by chemical method and the sliver evenness was determined by gravimetric method.

After treatment of blended samples (50 g) with a solution of sulfuric acid and weighing the washed and dried residue it was found that the content of steel fibers is from 9.3 to 9.5 % which is slightly lower, than the value established by the recipe. This decrease can be explained by the insignificant effect of sulfuric acid on the steel fibers.

Influence of the length of drafting zones of the draw frame machine RSB-D-40 on the sliver evenness was investigated. The Table 1 shows that the reducing the drafting zones leads to the significant decreasing of the blended sliver unevenness.

Table 1. Reducing the sliver unevenness after settings correction.

	Basic settings	Optimal settings
Break draft zone, mm	60	56
Main draft zone, mm	50	48
Cv (1m), %	1,39	0,98

For the optimal twist of two-ply yarn determining it was investigated the influence of the twist on the yarn properties. During the research the hypothesis was put forward that as a result of strands folding not only the improvement of mechanical properties compared to ring-spun yarn occurs but also the electrical resistance decreases.

Determination of the electrical resistance of simples of yarns of different structure and fiber composition was carried out using instrument ИЭСТП-2 according to the standard method [6].

For determination of yarns tensile properties in accordance to ASTM D2256 tensile testing machine Time WDW-20E was used.

3. Results

The optimal settings provide the best complex of mechanical properties of investigated yarns indicated in the Table 2.

Analyzing the data of Table 2, the following conclusion can be made. The adding of polyester fiber instead of cotton fiber into the yarn leads to the increasing in its breaking tenacity by 30 - 40% and breaking elongation by 2,5 - 2,7 times depending on its structure. Also increases the coefficient of variation of yarn breaking tenacity which is explained by the greater unevenness of the yarn due to the lack of combing process.

As a result of the yarns plying on twisting machines their breaking tenacity increases by 4 - 10 % and the elongation also rises. Coefficient of variation of the breaking tenacity is significantly reduced.

Table 2: Mechanical properties of single and ply electro conductive yarns

Parameters	Cotton – 90 %, Bekinox – 10 % ring-spun yarn	Polyester – 90 %, Bekinox – 10 % ring-spun yarn	Cotton – 90 %, Bekinox – 10 % ply yarn	Polyester – 90 %, Bekinox – 10 % ply yarn
Linear density of yarn, tex	20	20	20×2	20×2
Twist, tpm	700	730	500	550
Breaking tenacity, cN/tex	14,72	20,29	16,12	21,04
Coefficient of variation of breaking tenacity, %	10,0	17,2	5,69	6,55
Elongation, %	4.12	12.6	5,75	15,36

It can be noted that, due to the low value of the breaking elongation (1 %) the steel fibers either are broken earlier than other fibers during the yarn stretching or are pulled out. So, the strength of these fibers does not contribute to the blended yarn breaking force. The force-elongation curves (Figs. 2 and 3) of all yarn samples did not reveal the moment of breaking of the fibers Bekinox®.

The absence of these fibers influence on the yarn strength is explained by the fact that their average content in the cross section of the yarn is only 2,2 and the total breaking force does not exceed 6,5 % of the total strength of cotton fibers and 3,5 % of the strength of polyester fibers. All force-elongation curves have an almost linear appearance with a slight curvature on the left side, which may be due to both the breaking of Bekinox® fibers and the non-linearity of the tensile curves of cotton and polyester fibers.

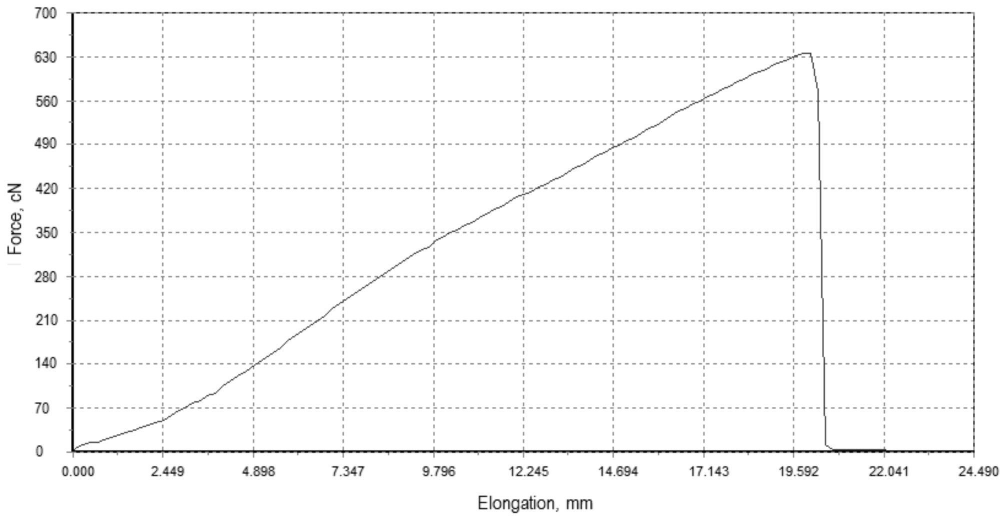

Figure 1. Force-elongation curve of yarn (90 % cotton/ 10 % Bekinox®).

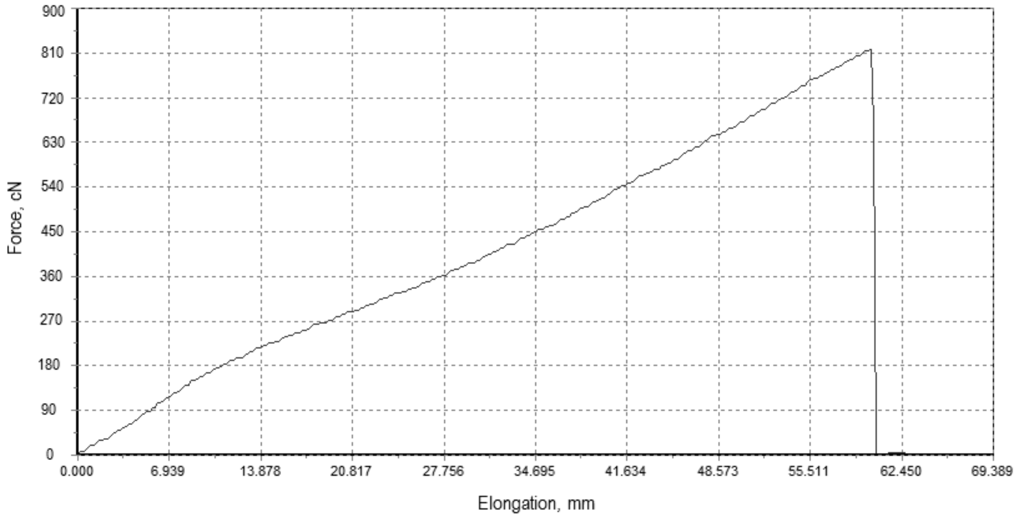

Figure 2. Force-elongation curve of yarn (90 % polyester/ 10 % Bekinox®).

To assess the effect of Bekinox® fibers on the electrical resistance of blended yarn in the next step we tested two samples yarns without Bekinox® fibers (19,3 tex cotton yarn and 18,5 tex polyester yarn).

Testing showed that the values of electrical resistance of these samples are following: for cotton yarn – 1.15 × 10^9 Ohm; for polyester yarn – 1.2 × 10^{10} Ohm.

This inequality is explained by significant difference in the humidity of the samples of yarn. Researches have shown that the addition of 10 % fibers Bekinox® into the blends noticeably reduces its electrical resistance of yarns of linear density 20 tex. Further the electrical resistance of the 2-ply yarns samples was checked. It was found that after plying the electrical resistance of the yarn decreases. However, for two types of blended yarns the influence of this process was different (Fig. 3).

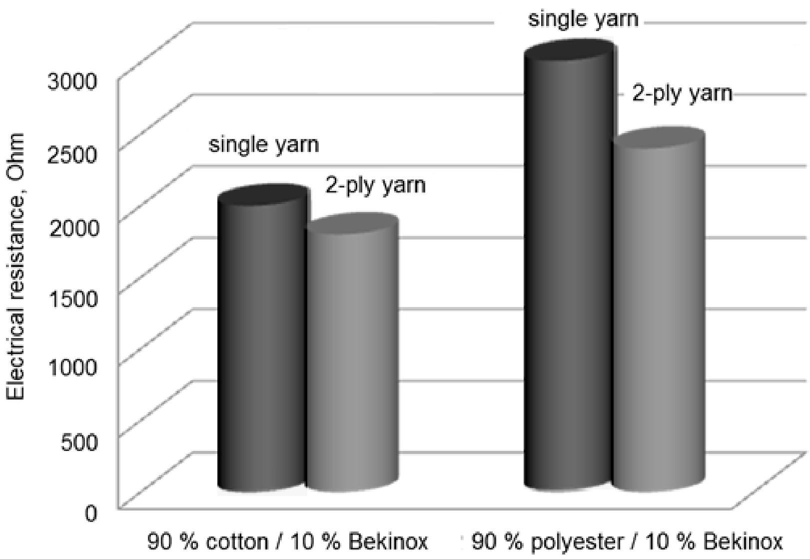

Figure 3. Influence of yarns plying including Bekinox® fibers on their electrical resistance.

The difference of the values obtained for single yarns and 2-ply yarns is checked using T-test. For cotton / Bekinox yarn $t_{obs} = 3{,}761$, for polyester / Bekinox yarn $t_{obs} = 5{,}122$. The critical value $t_{28,\,0{,}05} = 2{,}048$. As for both yarns type $t_{obs} > t_{28,\,0{,}05}$ the difference of the values is proven.

For yarn of polyester / Bekinox® the electrical resistance was reduced by 20 %, while for cotton / Bekinox® fibers this property decreasing was only 5 %. There are a number of factors influenced on yarn electrical resistance including the conductive fibers percentage, their location in the yarn and the properties of the rest fibers, such as their moisture content. However, if we talk about the dissimilarity in the electrical resistance change for the yarn of a certain composition because of plying as the main factors can be considered of difference of fiber migration inside yarns and the yarns hairiness.

To verify this assumption development of simulation model of ring-spun yarn was based on Martindale model of fiber assemblies. So, we considered that the number of ends of electrically conductive fibers in yarn cross section follows Poisson distribution.

The Poisson distribution is one of the simplest discrete probability distributions of random variables. To use it, no preliminary experimental studies are required. This distribution is used to develop mathematical models of ideal fiber assemblies. Despite the fact that it does not allow obtaining real values of the yarn unevenness, it makes it possible to determine the factors affecting the quality indicators of the yarn, in this case, the average number of contacts between stainless steel fibers. In addition, simulation based on the use of Poisson's distribution allows one to explain the experimentally revealed trends.

Usually yarn refers to one-dimensional textile materials in contrast to two-dimensional fabrics and three-dimensional goods. In most cases, this fact is taken into account when constructing its mathematical model. However, for simulation of inner structure of yarn it was considered as a three-dimensional object in which the configuration of each fiber has a complex shape due to joint migration in sections along the entire length of the fiber. The migration of fibers in the model under development is a significant phenomenon that determines the occurrence of contacts between fibers.

In the model it was assumed that during the yarn formation on a ring spinning machine each fiber trailing end necessarily forms a hair. This hypothesis is based on the following idea. In the twisting triangle most of the fibers are clamped both in front roller nip line and in twisting point of yarn.

In this zone fibers tend to move to the axis of the yarn and push out the trailing ends of the fibers which are no longer clamped in the front roller nip line. In this case, the trailing ends of such fibers form hair the length of which is comparable to the length of the twisting triangle. Thus, the development of the model is greatly simplified if we assume that all the rear ends of the fibers are in the outer layer of yarn. It is more convenient to choose the direction of simulation not from the leading ends of the fibers to the trailing ends, but vice versa.

For the yarn structure simulation the following initial data were taken: linear density of the yarn, percentage of electrically conductive and non-conductive components, fiber density of each component, fiber length of the conductive component, as well as the estimated migration parameters of the conductive fibers.

It is important to note that during the simulation only the positions of the electrically conductive fibers were determined, and the rest fibers were considered as the insulating surroundings. On the Figure 4 the result of one yarn cross section simulation is presented as the example. In this Figure, the cross-section of the yarn is limited by a solid line, and the cross-sections of electrically conductive fibers are shown by dotted lines. The Roman numerals show the cross-sectional number of the yarn in which the fiber trailing end originated during the simulation.

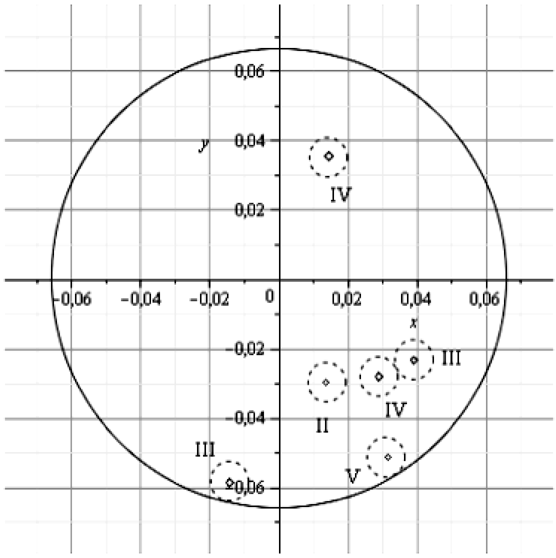

Figure 4. The result of one yarn cross section simulation.

In this example, the fifth cross section of the yarn is shown, provided that the distance between the sections is 1 cm. The figure shows that the trailing end of conductive fiber V situated on the surface of the yarn. The fibers whose trailing ends are in sections II and IV migrated towards the yarn axis. In the figure there are two fibers cross sections the trailing ends of which are located in section III. One of them is also located inside the yarn but another fiber migrated to its surface. The figure shows that due to the fibers migration a contact arose between fibers III and IV.

The simulation of twisted yarn was based on the following assumption. When deforming cross sections of single strands in the structure of twisted yarn all contacts between the electrically conductive fibers are retained while the fibers located on the surface of the strands in the contact zone form new contacts (Fig. 5).

Simulation of yarn structure shows that the average number of contacts between the electrically conductive fibers increases with the rise linear density of the yarn and with percentage of conductive fibers.

Taking into account the nominal fiber length of 47 mm, as a result of simulation it was determined that in a single ring-spun yarn with of linear density of 20 tex (10 % Bekinox®) the average number of contacts on this length is 1,29. If the linear density of the single ring-spun yarn is increased twice till 40 tex the average number of contacts rises to 2,23. For 2-ply yarn 20 tex × 2 the value of the indicator is 2,59 that is, it increases by 16 % that for the single ring-spun yarn of the same linear density. These results are obtained by simulation of a piece of yarn 50 m long.

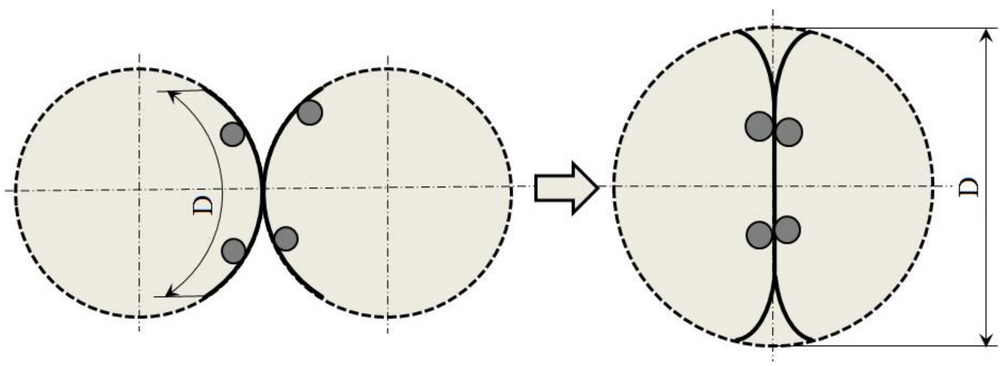

Figure 5. Creation of the fibers Bekinox® contacts in 2-ply yarn.

The average number of the conductive fibers contacts can differ from simulation results for several reasons. On the one hand, the number of contacts may slightly decrease due to the unevenness of the conductive component in the yarn. On the other hand, the actual arrangement of the fibers in the yarn is not completely random. Since the technological process contains only one passage of draw frame the connection between the Bekinox® fibers is not broken, which contributes to the contacts number increasing. Despite the differences in the actual distribution of fibers Bekinox® in the 2-ply yarn and the simulation results the effect of the strands folding is experimentally confirmed.

It should be noted that an increase in the number of contacts between electrically conductive fibers leads to decrease of the yarn electrical resistance, although the changes in these values are not proportional.

4. Conclusion

1. It is found that the addition of 10 % stainless fibers into the blends reduces its electrical resistance in $10^5 – 10^6$ times.
2. Experimental results show that after plying the yarn conductivity increases. However, this degree of this effect depends on the type of non-conductive fiber (cotton or polyester).
3. Based on the yarn structure simulation it is proven that plying of two strands leads to yarn conductivity increasing because of rise of the contacts number between stainless steel fibers on their surfaces.

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