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EVALUATION OF PHYSICO-MECHANICAL AND ELECTRICAL PROPERTIES OF RING- AND ROTOR-SPUN COTTON/STAINLESS STEEL CONDUCTIVE YARNS

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Abstract: *Nowadays, conductive yarns are widely used in various applications due to their ability to conduct electricity while preserving the characteristics of conventional textiles. They are commonly integrated into fabrics for antistatic protective equipment, enabling the dissipation of electrical charges and reducing risks in sensitive settings. When metallic fibers are blended with other fibers to produce conductive yarns, two key questions arise: what is the minimum amount of metallic fiber required to achieve adequate electrical conductivity, and which spinning technology should be used to ensure an optimal balance between performance and cost? The objective of the study was to evaluate the effects of the spinning technique and the metallic fiber content on the performance of conductive yarns developed for charge dissipation in industrial settings. Conductive yarns of 37 tex were produced by ring and rotor spinning from two cotton–stainless steel fiber blends (96/4 and 81/19). Due to their compact structure, characterized by a high degree of fiber straightening and parallelization, ring-spun yarns exhibited higher strength, lower elongation at break, and lower linear resistivity compared to rotor-spun yarns. Conversely, as a result of fiber back-doubling in the rotor groove, rotor-spun yarns showed improved uniformity in both linear density and strength. Increasing the proportion of stainless steel fibers led to an increase in tensile strength, accompanied by a decrease in both yarn diameter and elongation at break. At the same time, the higher stainless steel content reduced the linear resistivity of the yarn, thereby enhancing its ability to dissipate electrical charges.*

Key words: *antistatic yarns, stainless steel fibers, cotton-metal fiber blends, ring spinning, rotor spinning, yarn resistivity*

1. INTRODUCTION

Electrostatic charges that build up on the surface of fabrics due to triboelectric charging can lead to the ignition of flammable substances in explosive atmospheres, damage to electronic components, or contamination of precision equipment in cleanrooms [1,2]. To prevent the buildup and discharge of static electricity, conductive materials are integrated into textiles to enable efficient dissipation of electrical charges [3,4].

One of the solutions to obtain textiles with antistatic properties is the use of conductive yarns. Currently, conductive yarns can be obtained through several methods: blending conductive fibers with conventional fibers, core-spun yarn technology (wrapping a conductive filament with a sheath of conventional fibers), twisting or plying conductive filaments with textile yarns, coating or plating conventional yarns with conductive materials, using intrinsically conductive polymers, and incorporating carbon nanotubes or graphene [5]. The choice of the method depends on the targeted conductivity level, mechanical performance, comfort, durability, manufacturing cost, and final application, such as antistatic textiles, sensors, smart textiles, or electromagnetic shielding materials [6, 7].

In this paper, conductive yarns from blends of natural fibers, such as cotton, with conductive fibers, such as stainless steel are analyzed. Combining the two types of fibers in a blend leads to the obtaining of textile materials that retain the hygroscopic properties, air and water permeability as well as the softness conferred by cotton, and at the same time ensure electrical conductivity and antistatic protection, properties conferred by metallic fiber. Ichim et al. analyzed the properties of 29.4 tex rotor yarns spun from cotton–stainless steel blends in different ratios (96/4, 92/8, and 88/12) and reported yarn linear resistivity values ranging from 2.02×10^9 Ω/cm to 2.1×10^3 Ω/cm.

Producing high-performance yarns from such blends requires a careful selection of the spinning technology. Ring spinning is one of the oldest and most widely used methods of yarn production, valued for the superior quality and strength of the finished product. In contrast, rotor spinning is a more modern method, characterized by higher production speed and lower operating costs, but often associated with lower yarn quality [8]. In this sense, the comparison between ring spinning and rotor spinning becomes essential, not only for optimizing the functional properties of the yarns, but also for balancing production costs according to the requirements of the final application.

The proportion of metallic fibers has a considerable impact on the mechanical characteristics of the yarn, such as tensile strength and elongation, while also influencing the aesthetic appearance, uniformity and behavior in the spinning process. A content that is too low may impair yarn performance, whereas excessive content can adversely affect hand, increase production costs, and reduce the processability of the blend.

The objective of this research was to evaluate the effect of spinning technology and metallic fiber content on the properties of yarns designed for antistatic protective equipment. This study investigates the physico-mechanical and electrical properties of 37 tex conductive yarns produced by ring and rotor spinning from two cotton/stainless steel fiber blends (96/4 and 81/19).

2. MATERIALS AND METHODS

The stainless steel fibers used in the experiments, provided by Hunan Huitong Advanced Materials Co., Ltd. (China), were characterized by the following properties: a length of 50 mm, a linear density of 390 mtex, a tenacity of 17.9 cN/tex, an elongation at break of 1%, and a density of 7.85 g/cm^3.

The cotton fibers, supplied by the Faculty of Industrial Design and Business Management (Romania), had the following characteristics: an average length of 27.3 mm, a linear density of 259 mtex, a tenacity of 9.6 cN/tex, an elongation at break of 6%, and a density of 1.52 g/cm^3.

The stainless steel fibers, in sliver form, were blended with cotton fibers during the first passage through the draw frame. To ensure a homogeneous distribution of the metal fibers within the sliver cross-section, three draw frame passages were carried out.

To obtain a blend of 81% cotton and 19% stainless steel, seven cotton slivers and one stainless steel sliver were fed into the first draw frame passage. In the subsequent passages, eight slivers of the cotton–stainless steel blend were processed.

To obtain a blend of 96% cotton and 4% stainless steel, seven cotton slivers and one stainless steel sliver were fed into the first draw frame passage. In the second passage, six cotton slivers and two slivers of the cotton–stainless steel blend were processed, while in the final passage, eight slivers of the blend were fed into the draw frame.

Yarns were spun with a twist multiplier of 112 using common practices in cotton spinning mills, employing both rotor spinning and ring spinning methods.

Yarn properties were evaluated under standard atmospheric conditions of 20 ± 2 °C and 65 ± 2% relative humidity. The linear density of the yarns was determined in accordance with the SR EN ISO 2060 standard. Tensile properties were measured using a Tinius Olsen H5 K-T tensile tester equipped with a 250 N load cell, following the EN ISO 2062 standard and using a gauge length of 500 mm. Twist measurements were carried out on a Mesdan twist tester in accordance with the EN ISO 2061 standard, using a clamping distance of 250 mm. The yarn diameter was measured using a Mesdan microscope fitted with a Leica objective and camera, with images captured at 4× magnification.

To determine yarn resistivity, the specimen, consisting of an insulating plate around which the test yarn was wound, was placed in contact with the bar electrodes of the measuring device. A known voltage was applied across the electrodes, and the electrical resistance of the specimen was measured with an accuracy of ±20% using the voltmeter–ammeter method (STAS 11014-88). The measured electrical resistance was then used to calculate the linear resistivity of the yarn.

3. RESULTS AND DISCUSSION

The properties of rotor- and ring-spun yarns with a linear density of 37 tex (Nm 27), manufactured from cotton/stainless steel fiber blends in proportions of 96/4 and 81/19, are shown in Table 1.

Table 1: *Yarn properties*

Properties	**A1: 96/4 cotton/stainless steel**		**A2: 81/19 cotton/stainless steel**	
	Ring-spun yarn	**Rotor-spun yarn**	**Ring-spun yarn**	**Rotor-spun yarn**
Linear density, [tex]	37.08	36.32	37.58	36.04
CV of linear density, [%]	2.69	1.48	2.17	1.18
Diameter, [µm]	0.306	0.311	0.293	0.298
Twist, [tpm]	578.80	579.2	578.40	580.8
Breaking force, [cN]	374.1	234.2	431	340.7
CV of breaking force, [%]	11.89	9.92	10.26	8.30
Elongation at break, [%]	5.81	6.69	5.41	7.27
Linear resistivity, [Ω/cm]	1.03 x 10^9	1.9 x 10^9	728.2	1392.8

The average values of the yarn linear density fall within the variation limits permitted by the standard for a yarn with a nominal linear density of 37 tex, namely between 35.6 tex and 38 tex. The coefficient of variation (CV) of the linear density is higher for the ring-spun yarn than for the rotor-spun yarn, regardless of the blend. This can be explained by the fact that, in ring spinning, variations in the mass per unit length of the fed roving are transmitted directly to the yarn. In contrast, in rotor spinning, the fibers in the fed sliver are individualized by the action of the opening roller and transported separately to the rotor. Within the rotor, the fibers undergo random redistribution and blending as they are deposited in the collection groove. This process of fiber separation and blending helps to even out the strand formed in the rotor, thereby reducing the effect of fluctuations in the fed sliver [8,9]. Increasing the proportion of metal fibers in the yarn leads to a reduction in linear density irregularity, as stainless steel fibers exhibit more uniform linear density than cotton fibers.

For both blends, the diameter of the rotor-spun yarn is slightly greater than that of the ring-spun yarn, even though the rotor-spun yarns are marginally finer. As the proportion of stainless steel fibers increases, the yarn diameter decreases, which can be explained by the smaller thickness of steel fibers compared to cotton fibers. However, the diameter differences between the yarn variants are small.

Fig. 1 shows the microscopic appearance of 81/19 cotton–stainless steel yarns. The ring-spun yarn exhibits a smooth, compact structure, with fibers that are highly straightened and parallelized, arranged in concentric helical layers with Z twist. In contrast, the rotor-spun yarn displays a structure composed of two distinct layers. The core consists of fibers twisted in the Z direction, while the outer layer is formed either by fibers wrapped nearly perpendicularly around the core, creating so-called "belts," or by fibers with both S and Z twist directions that envelop the core in a net-like manner. Fig. 1b also highlights the presence of free loops—formed by fibers whose both ends are embedded within the yarn mass—in the rotor-spun yarn structure. This distinct structural configuration results in greater bulkiness compared to conventional ring-spun yarn [9,10].


a

b

***Fig. 1**: Longitudinal view of the yarns (magnification 4x)*
a) ring-spun yarn, b) rotor-spun yarn

Table 1 shows that the breaking force of conventionally spun yarns is higher than that of rotor-spun yarns, regardless of the blend variant. In contrast, rotor-spun yarns exhibit lower variability in strength compared to the variation in breaking force observed in conventional yarns. This characteristic of rotor-spun yarns ensures a reduced number of breaks during subsequent processing stages, resulting in higher efficiency in weaving and knitting operations [11].

For yarns produced using the same spinning method, an increase in the proportion of metal fibers leads to higher breaking force and lower variability in breaking force.

The ring-spun yarn exhibits a lower elongation at break compared to the rotor-spun yarn. In the case of ring-spun yarn, an increase in the proportion of metal fibers results in a decrease in elongation at break.

Figure 2 shows the force–elongation curves for ring-spun and rotor-spun yarns with a nominal linear density of 37 tex, produced from blends of 96% cotton and 4% stainless steel (A1), and 81% cotton and 19% stainless steel (A2), respectively.

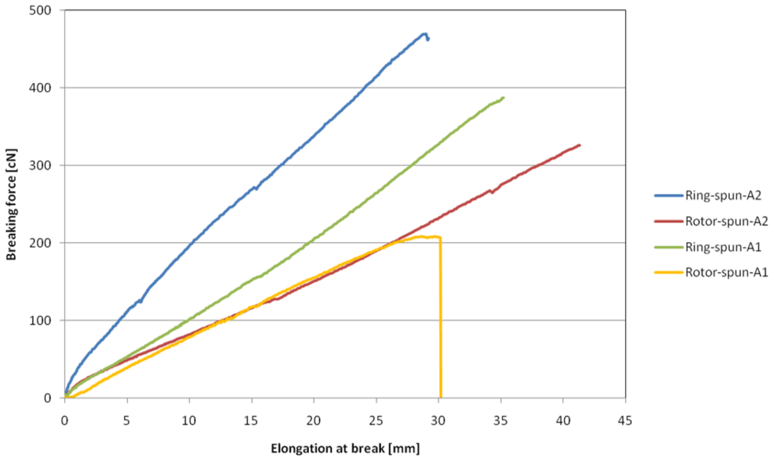

Fig. 2*: Force-elongation curves*

The force–elongation curves of the ring-spun yarns have a steeper slope than those of the rotor-spun yarns, indicating that the ring-spun yarns are stiffer and have a higher modulus of elasticity. This means that, at the same elongation, a higher tensile force is required for the ring-spun yarn, confirming that it is less elastic than the rotor-spun yarn.

From Table 1, it can be observed that the linear resistivity of the conventional yarn is approximately twice as low as that of the rotor-spun yarn. Therefore, the conventional yarn offers less resistance to the passage of electric current, conducts electricity more easily, and generates lower energy losses in the form of heat.

Linear resistivity depends on the internal structure of the yarn, the contact between fibers, the distribution of conductive fibers, as well as the density and homogeneity of the yarn. The conventional yarn is more compact, with straightened and parallel fibers arranged in helical layers, whereas the rotor-spun yarn is more voluminous, with fibers in the outer layer arranged in a more disordered manner. Since the contact surface between fibers is larger in the conventional yarn, its electrical conductivity is higher, resulting in lower linear resistivity.

In ring spinning, due to the higher tension applied during yarn formation, the metal fibers are better integrated among the cotton fibers, reducing the likelihood of fiber protrusion and improving both durability and conductive stability. However, the process is slower, more expensive, and may require equipment adaptations to process stainless steel fibers effectively, as these are more rigid and abrasive than natural fibers.

In comparison, rotor spinning is faster and more economical. However, the manner in which fibers are incorporated into the yarn—characterized by the fact that, during twisting, only one end of the fiber is bound into the yarn while the other remains free—results in a more random fiber orientation. Consequently, stainless steel fibers may be unevenly distributed, which can negatively affect the conductive efficiency and stability of the yarn during use.

For the same spinning technology, increasing the proportion of metal fibers leads to a decrease in yarn linear resistivity, and therefore to improved performance in dissipating electrical charges.

For a textile material to be used in antistatic protective clothing, its surface resistance must be lower than $2.5 \times 10^9\ \Omega$ [12]. The linear resistivity values of all the analyzed yarns indicate their suitability for antistatic applications. However, since this requirement refers specifically to surface resistance, further investigation is needed to assess the behavior of fabrics produced from these yarns.

4. CONCLUSIONS

The experimental research aimed to investigate the influence of the spinning technology and the proportion of metallic fibers on the properties of yarns intended for antistatic protective equipment.

Owing to their compact structure, in which the fibers exhibit a high degree of straightening and parallelization, ring-spun yarns showed higher strength, lower elongation at break, and lower linear resistivity than rotor-spun yarns. On the other hand, due to the back-doubling of fibers in the rotor groove, rotor-spun yarns exhibited greater evenness in linear density and strength.

An increase in the proportion of stainless steel fibers led to higher tensile strength, while both yarn diameter and elongation at break decreased. At the same time, the rise in stainless steel content reduced the yarn linear resistivity, enhancing its capacity to dissipate electrical charges.

In the current industrial context, any technological choice must be evaluated not only in terms of technical performance, but also in terms of economic efficiency. Ring spinning produces yarns with superior properties but involves higher production costs. In contrast, rotor spinning enables faster and more cost-effective production.

The choice of spinning method should be based on a well-balanced cost–performance ratio: where performance requirements are high, a higher price for superior yarn can be justified; conversely, for high-volume applications with moderate requirements, a technology that optimizes costs without significantly compromising functionality is preferable.

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