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DEVELOPMENT OF STRETCHABLE CONDUCTIVE HYBRID YARN FOR WEARABLE ELECTRONICS APPLICATION

İbrahim Adel Khamis Ahmed[1], Münire Sibel Çetin[1], Ayşe Feyza Yılmaz[1], Aslı Tunçay Atalay[2], Gökhan İnce[3], Özgür Atalay[1(*)]

[1] Istanbul Technical University, Faculty of Textile Technologies and Design, İstanbul, Turkey
[2] Marmara University, Faculty of Technology, Textile Engineering Department, İstanbul, Turkey
[3] Istanbul Technical University, Faculty of Computer and Informatics Engineering, İstanbul, Turkey
(*) *Email:* atalayoz@itu.edu.tr

ABSTRACT

Wearable electronics and electronic textiles are becoming increasingly important as technology advances. To supply the conductivity required in wearable electronics, investigations on the integration of electronic components with textiles by adding conductivity to fabric structures, as well as the development of items generated in this manner in terms of human comfort, have grown. The base materials, i.e., yarns, should be as flexible, thin, and light as possible during the manufacturing and incorporation of electronic textile components (sensors, transmission lines, connections, etc.) into wearable products in order to tolerate the rigid structure and low elasticity of the metallic parts that provide conductivity. In traditional yarn production processes, hybrid yarn production is regularly carried out with numerous modifications. Problems arise in these manufacturing processes due to the fact that the core fiber cannot be precisely positioned in the center of the yarn, the fluctuation of yarn strength throughout the yarn, and the increase in yarn irregularity. The "Direct-Twist - 2C" twisting machine, which can manufacture hybrid-yarn without modification, was employed in this investigation. Unlike previous approaches, hybrid-yarn manufacturing with Direct-Twist aims to overcome the problems found in other ways since the core can be positioned exactly in the center of the yarn. A new hybrid-yarn was generated in this work by employing spandex in the core and silver-plated conductive yarn in the coating. Tensile and resistance measurements performed within the scope of the study demonstrate that a stretchable conductive hybrid-yarn structure with a homogeneous distribution of core and coating structures is achieved.

KEYWORDS

Hybrid-yarn, stretchable conductive yarn, electronic textiles.

INTRODUCTION

Given with the growing interest in on-body monitoring wearable sensors such as the use of electrodes that record the heartbeat rate; pressure sensors that track the joints and limps; as well as other devices that include heating elements and antennas comes the necessity for electrical transmission lines. To keep up with such fabric properties as stretchability, flexibility, and comfort, these transmission lines must be highly stretchable without changing their electrical conductivity.

Blending carbon-black particles into elastic spun yarns [1] or conductive particle coating on fibrous thermoplastic yarns [2,3] are two successful ways for manufacturing conductive yarns with near to the needed qualities. Other approaches include core-spinning with conductive fibers as the cover and rubber-based yarn as the core [4], and also a direct-twist approach is used to cover an elastic core with stainless steel staple fibers [5]. Unfortunately, these approaches do not satisfy both qualities under tension; they either lose conductivity ("the resistance increases exponentially") or do not give sufficient elasticity.

Our goal is to create a highly stretchy conductive yarn with low resistance fluctuations within its stretchable range.

In this article, we show how we used the direct-twist method to make a hybrid yarn with highly conductive yarns "SHIELDEX® electrical resistivity 500 ohm/m" as the cover and an elastomer core "Hyosung TNC Spandex®" as the core.

We chose the direct-twist method due to its ease of manufacture and wide range of parameters for dialing in the desired result, and we chose from various arrays of alternative yarn arrangements.

MATERIALS AND METHODS

Materials

In this study, three different trial sets were created to determine the basic production parameters in hybrid yarn production with the Directwist 2C twisting machine. The first set were conducted using basic cotton yarns to investigate the required parameters. In this way, the working parameters at which maximum coverage can be achieved were determined. The basic properties of the yarns in the three sets studied are presented in (Table 1).

Table 1. Basic properties of yarns in high conductivity and stretchable hybrid yarn production trial sets.

Trials	Core yarns	Cover Yarns
First	Nylon 70/90 Elit Gipe® & 210/70 Çombaş®	Cotton “Ne 36”
Second	Spandex “560 dtex”	SHIELDEX “110 dtex, 34 filaments”
Third	Spandex “560 dtex”	SHIELDEX “235 dtex, 34 filaments”

In the second and third sets, different thicknesses of conductive yarns were used in the outer layer as coating and elastomeric yarn was used as the core.

Methods

Parameters

In this study, combinations of different production parameters were tried on a Directwist 2C machine, using yarns whose basic properties were given under the heading of material. In the trials, changes were made in the parameters of the number of coating yarn, elastomeric yarn feed rate and twist amount (Table 2).

Table 2. Parameter combinations worked in trial sets.

Trials	Turns/meter	feeding rate “e %”	No: of cover yarns	Twisting direction
First	550:750	Maximum tension	2	S
Second	1000	70%	2	S
Third	1000	40-30%	1	Z

While working with the first set, we concluded that the most effective parameter to achieve sufficient coverage was "Turns/meter", and secondly was the feed rate of the elastomeric yarn “e %”. (Fig. 1) shows the combinations performed using the automatic elastomer feeding mechanism to determine the appropriate feed percentage "e%".

After determining the sufficient covering parameters, the second set of trials were conducted to mimic the parameters of the first set and to achieve similar results while using the established yarns materials of exclusively rubber-based core “560 dtex Spandex” with double “110 dtex, 34 filaments SHIELDEX” conductive yarns.

When two covering yarns were used, problems such as twisting triangle with different tensions occurred before the yarns enter the machine and further complexity of the coating were encountered such as the two cover yarns sometimes would twist on each other before wrapping the core, also duo to the high number "T_r/m" used with relativity fine covers it was more susceptible to breakages. For these reasons, the third set was tested using a single covering yarn.

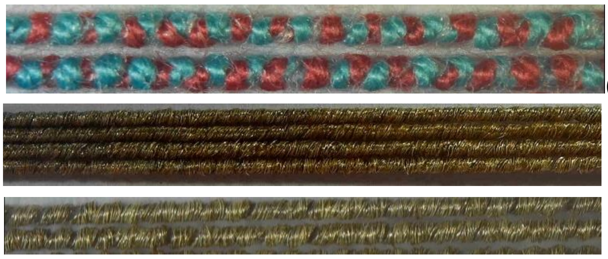
(a)
(b)
(c)

Figure 1. First set: "Nylon 70/90 Elit Gipe" covered by two cotton yarns "Ne 36" (a), Second set: "560 dtex Spandex" covered by two "110 dtex SHIELDEX" (b) and Third set: covered by one "110 dtex" (c).

In the third set of trials, we concluded that the best parameters for covering the core with constant production are "1000 T_r/m" & with feeding rate of elastomer core at "30-40%" using only one cover yarn for simplicity of production.

Another attempt to further ease the production is to remove any unwanted friction by changing the twist direction to avoid any latching of the cover yarns on any silver residue that might accumulated on the yarn guides from previous trials, knowing that the twist direction will not affect any of the desired outcomes sense its only one cover yarn with no pre-twist installed in its filaments.

As for lowering the "T_r/m" number for less aggressive production, you have to lower the feeding rate of the elastomer core accordingly to achieve similar results; Elsewise the covering will not be sufficient and the covering loops will be free to slide and accumulate in certain areas instead of another. Similar to "T_r/m" higher numbers is the feeding rate of the elastomeric yarn "e %" lower percentages will yield a stiff yarn with high potential of false twists.

Testing

Due to the complications of the second set of trials stated above and the simplicity of the third set parameters, it was deemed that third set is the way to continue manufacturing and testing.

To compare the stretchability of the manufactured hybrid-yarn with the "SHILELDEX" conductive yarn, a five "10 cm" samples were tested on a "James H. Universal Strength Tester" with "120 N loading cell" at "50 mm/sec extension rate" (Fig. 2. a).

(a) (b)

Figure 2. J. H. - Universal strength tester with "120 N loading cell" (a), conductivity tested by UNI-T UT33B digital multimeter on a J. H. Tensile Testing Equipment with increments of "5% elongation" (b).

For conductivity testing, a five "10 cm" samples were tested by a "UNI-T UT33B Digital Multimeter" on a "James H. Tensile Testing" with "5% elongation" increments (Fig. 2. b).

RESULTS AND DISCUSSION

Tensile Strength

The tensile test results concluded that the hybrid-yarn samples of “10 cm” can reach an elongation of up to “220 %” on average before braking (Fig. 3. a), which is “* 8” more than the conductive yarns elongation of only “28 %” (Fig. 3. b).

For future attempts this high stretchability of the hybrid yarn can be sacrificed to lower the total final count using “finer / weaker” core since this “220 %” elongation is well above any wearable applications.

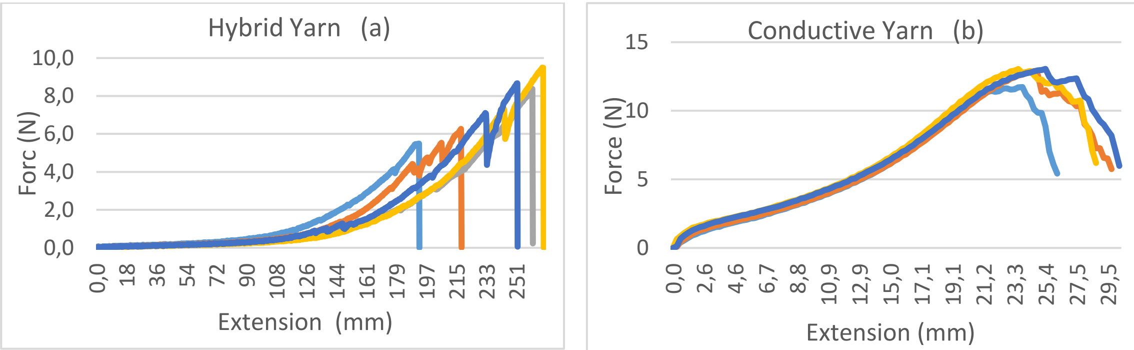

Figure 3. Extension graph of the hybrid yarn (a), extension graph of the conductive yarn (b).

Conductivity

The conductivity test results concluded that there is minimum increase in resistance with a constant rate of “0.2~0.3 Ω” with “5% elongations” increments (Fig. 4).

Similar to the tensile test, the future attempts will aim to eliminate any conductivity changes under human body stresses.

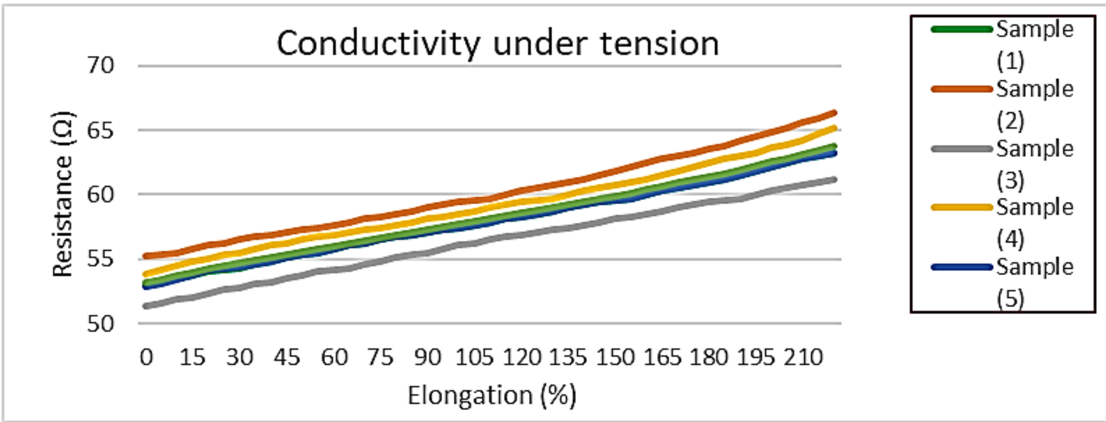

Figure 4. Hybrid-yarn resistance increased with constant rate with the elongation increments.

able 3. The standard divisions and the coefficients of variations for tensile and conductivity tests.

Coefficients	Conducive Tensile S.D	Conducive Tensile C.V	Hybrid Tensile S.D	Hybrid Tensile C.V	Hybrid Conductivity S.D	Hybrid Conductivity C.V
Min	0.14	0.025	0.01	0.099	1.11	0.019
Max	2.46	0.238	3.26	0.599	1.78	0.028
Avg	0.34	0.050	0.84	0.353	1.29	0.022

CONCLUSION

In wearable electronics, in order to obtain structures with high homogeneity and low rigidity, it is necessary to give stretchability to conductive yarns and to benefit from knitting technology.

In this study, we successfully manufactured a hybrid yarn, where the properties of conductivity and stretchability are combined. As a result of the tests made on the developed yarns; It was observed that the stretchability of the conductive hybrid-yarns increased, they had a homogeneous structure and their conductivity was preserved. In the continuation of this study, it is aimed to calculate the core and cover yarns counts required to provide the final yarn count suitable for knitting technology and to perform physical tests to determine the performance of knitted structures to be produced with new stretchable conductive hybrid-yarns for wearable electronics.

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