



## STUDY OF THE CONDUCTIVITY AND RESISTIVITY OF CONDUCTIVE YARN

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**Abstract:** *The new epoch of the textile industry is very focused on the development of smart textiles, which provide added value to conventional textiles and break into the market with more impact. For this work, a characterization study has been carried out on several samples of textile yarns with conductive properties. The yarns studied are from the manufacturer Bekintex and the samples studied are referenced as Bekinox VN 14/1x90/100z, Bekinox VN 15/1x90 and Bekinox VN 8/1x275. Representative resistivity values in the order of  $10^{-6}$  and  $10^{-7}$  (for example,  $1.0239 \cdot 10^{-6}$  and  $3.2569 \cdot 10^{-7}$ ) have been obtained; these very small values confirm that the fibers are good electrical conductors, while the variation between samples indicates that yarn structure, filament diameter and test configuration influence electrical behavior. In order to carry out the appropriate measurements, an assembly was made with two multimeters and a power supply, in order to vary the voltage and record the intensity and resistance at the same time. Depending on the different conductive characteristics of each filament, we can use them for smart textiles that require little resistivity to be able to feed some element or more resistivity to be able to use them as thermal emitters. This electrical selection also defines the possible contribution of the yarn to textile thermal comfort, either as a low-loss conductive path or as a localized Joule-heating element. The  $Q$  of the Joule effect was also calculated to assess the thermal emission of the same yarns.*

**Key words:** *metallic yarn, conductive yarn, smart textile*

### 1. INTRODUCTION

The economic experts of the textile world present smart textiles as the next generation of fibers, fabrics and articles to be produced thanks to their enormous possibilities and functionalities. They can be described as textile materials that think for themselves, for example, through the incorporation of electronic devices or intelligent materials. Many smart fabrics are already used in advanced types of clothing, mainly for protective and safety garments, although concepts of fashion, comfort and innovation are being successfully embraced [1–4].

One of the main reasons for the rapid development of smart textiles is the significant



investment made by the military industry [5–8]. This is because they are used in various projects such as winter jackets for extreme temperature conditions or uniforms that change color to improve camouflage effects.

Smart textiles provide evidence of the potential and enormous opportunities that can still be realized in the textile industry, in fashion or design, as well as in the technical textiles sector. On the other hand, these advances are the result of active collaboration between people from different disciplines: engineering, science, design, process development, business and marketing. Our daily life, in the coming years, will be significantly regulated by smart devices and many of these devices will be integrated into garments or different textile substrates.

There are two ways to develop electrical and/or thermal conductive fabrics, just as there are two types of materials, metals and polymers, that provide these properties. The same materials could be used for both conductivities (thermal and electrical). Indeed, both processes are similar and result from electronic agitation/conduction [9].

The first way uses finishes (pigments and print pastes) with a high metallic content but still retaining the flexibility required for clothing. From the addition of layers of nickel, copper, silver or carbon of various thicknesses, these finishes provide a versatile combination of physical and electrical characteristics that cover a wide variety of use demands. The second way consists of the direct use of conductive threads. The thread can be made up of a traditional base (cotton, wool, PES, etc.) and a metal core such as silver, copper, etc. or conductive polymer such as polythiophene [10], polyaniline, polyacetylene [11] and its derivatives.

Although there are many different brand names that market these materials, they all have the same main characteristics. They are light, durable, flexible and competitive and can be pressed, welded and integrated into the textile process. Although, as has been described, the use of smart textiles can be very diverse and different, in this work the research focuses on initial studies and characterization of certain filaments to achieve textiles with thermoregulable properties [12].

On the planet, many people are living and working in extremely cold places, so they require accessories or elements that allow them to maintain or increase the temperature of their body and their outerwear. A clear example of this type of need is that of the military or the traffic police. But common textiles made of cotton, synthetic fibers try to provide warmth by reducing heat loss that occurs through convection and conduction. What these types of garments do is trap the air between the layers of the textile article and thanks to the heat emitted by the human body, that air heats up and by reducing the loss of that heat it keeps the body warmer. In this way the classic method to keep warm is to wear more clothes, it has been proposed as an idea of "personal thermal management" as an efficient way of saving based on the idea of keeping the human body warm [13]. Many researchers seek to develop a textile that has integrated systems capable of responding to the variation of the external temperature, achieving another method to the classic described, thus managing to develop an effective method to obtain thermoregulable intelligent textiles [14], [15].

## 2. MATERIALS AND METHODS

In the first place will be carry out measurements on the independent metallic filaments, before their manipulations with other more conventional yarns. For this will be used the setup described above. First evaluation of the electrical conductivity was made. From here will come the material or materials that we will manipulate in a winder, to obtain the composite yarns that we will use in the weaving of the final textile.

Metallic yarns: Several samples of metallic yarns are used, one of a copper/tin alloy and several samples of steel provided by a producer of this type of yarn (Bekintex), these were Bekinox

VN 14/1x90/100z, Bekinox VN 15 /1x90 and Bekinox VN 8/1x275.

This study focuses on the characterization of the filaments, specifically on the conductive characteristics, which are what will give the textile development these differentiating characteristics. There are some magnitudes that will give information about the behavior of the material, these are the intensity (I) measured in amperes (A), the voltage measured in volts (V), the electrical resistance, measured in ohms ( $\Omega$ ) and resistivity ( $\rho$ ) [16]. To record these measurements, a power supply and two multimeters are mounted in series (Image 1), to simultaneously record the current and voltage measurements, subsequently calculating the resistance.

The electrical measurements were performed under controlled laboratory conditions, with the yarns conditioned for 24 h before testing at  $20 \pm 2$  °C and  $65 \pm 4\%$  relative humidity. Each sample was tested in dry state on an insulating support, the effective length between clamps was kept constant for each test, and the same multimeter/power-supply arrangement and contact points were used to reduce variation due to contact resistance.



*Fig. 1: Multimeter and power supply*

The thermal emission of heat that the yarns will give off by the Joule [17], [18] effect will also be quantified. This effect is defined as the amount of heat energy produced by an electric current, which depends directly on the square of the intensity (I) of the current, the time in minutes (t) that it circulates through the conductor and the resistance (R) that opposes it to the flow of current. Mathematically it is expressed with equation 1 shown below.

$$Q = I^2 \cdot R \cdot t \quad (1)$$

After the conductivity tests carried out, heat radiation tests are carried out by the joule effect. For this, different samples of filament are taken, and with the same assembly described above in which its resistivity is measured, a controlled electrical intensity is passed through, and the heat released is recorded. In order to measure this thermal emission, the filament is introduced into a container with ultra pure water (so that it does not interfere with conductivity) and the variation in water temperature is controlled in constant periods of time.

The Joule-effect tests were carried out in the same laboratory atmosphere. A 200 ml volume of ultrapure water was used for each test, with an initial temperature close to 24.6 °C, and the



temperature increase was recorded at five-minute intervals to compare the heating behavior of the different yarns.

### 3. RESULTS AND DISCUSSION

For each of the metallic yarns, several measurements of voltage and intensity were made and their resistivity was calculated (Tables 1-3), obtaining the corresponding formulas of said straight lines that can be extrapolated to other results that are desired to be calculated theoretically.

Values such as  $1.0239 \cdot 10^{-6}$  and  $3.2569 \cdot 10^{-7}$  represent very small resistivity values and therefore confirm that the tested fibers are good conductors of electricity. Nevertheless, the results are not identical for all samples: the observed variation is consistent with differences in filament diameter, yarn structure, sample length and contact conditions. Consequently, yarn selection must be linked to the final function of the smart textile, distinguishing between efficient electrical transmission and controlled resistive heating.

*Table 1: Bekinox VN 14/1X90/100Z*

V	I	R	D (cm)	L (cm)	$\rho$
7.76	0.152	51.0526316	0.0014	66.4	$1.1835 \cdot 10^{-6}$
4.83	0.0986	48.9858012	0.0014	66.4	$1.1356 \cdot 10^{-6}$
9.89	0.1994	49.5987964	0.0014	66.4	$1.1498 \cdot 10^{-6}$
14.19	0.28	50.6785714	0.0014	66.4	$1.1749 \cdot 10^{-6}$
16.78	0.33	50.8484848	0.0014	66.4	$1.1788 \cdot 10^{-6}$
22.8	0.46	49.5652174	0.0014	66.4	$1.1490 \cdot 10^{-6}$
32.1	0.63	50.9523811	0.0014	66.4	$1.1812 \cdot 10^{-6}$

*Table 2: Bekinox VN 15/1X90*

V	I	R	D (cm)	L (cm)	$\rho$
8.7	0.0818	106.356968	0.0014	159.9	$1.0239 \cdot 10^{-6}$
12.9	0.12	107.501145	0.0014	159.9	$1.0349 \cdot 10^{-6}$
16.9	0.1568	107.780612	0.0014	159.9	$1.0376 \cdot 10^{-6}$
20.8	0.1916	108.559499	0.0014	159.9	$1.0451 \cdot 10^{-6}$
24	0.21	114.285714	0.0014	159.9	$1.1002 \cdot 10^{-6}$
31.8	0.28	113.571429	0.0014	159.9	$1.0934 \cdot 10^{-6}$

*Table 3: Bekinox VN 8/1X275*

V	I	R	D (cm)	L (cm)	$\rho$
2.73	0.0374	72.9946524	0.0008	116	$3.1630 \cdot 10^{-7}$
7.98	0.108	73.8888889	0.0008	116	$3.2018 \cdot 10^{-7}$
11.6	0.1576	73.6040609	0.0008	116	$3.1894 \cdot 10^{-7}$
14.33	0.1937	73.980382	0.0008	116	$3.2057 \cdot 10^{-7}$
18.06	0.24	75.2511056	0.0008	116	$3.2608 \cdot 10^{-7}$
23.3	0.31	75.1612903	0.0008	116	$3.2569 \cdot 10^{-7}$
30.5	0.42	72.6190476	0.0008	116	$3.1468 \cdot 10^{-7}$



On the one hand we see the values obtained for thermal emission for voltage values (V) of 30 v. and a time of 60 seconds, with which the values calculated and shown in table 4 are obtained.

*Table 4: Thermal emission Joule Effect for each sample*

Sample	Voltage	Time (s.)	Q (Joule)
Bekinox VN 14/1X90/100Z	30	60	719.39
Bekinox VN 15/1X90	30	60	787.28
Bekinox VN 8/1X275	30	60	850.89

Finally, the thermal variation that occurs in the 200 ml of water in which each sample is immersed and the temperature variation that it experiences over time are shown. The results of each sample can be seen in table 5.

*Table 5: Thermal variaton*

t (min.)	Bekinox VN 14		Bekinox VN 15		Bekinox VN 8	
	Water °C	Increase °C	Water °C	t (min.)	Water °C	Increase °C
0	24.6	0	24.6	0	24.6	0
5	25.6	1	25.6	5	25.6	1
10	27.4	2.8	27.4	10	27.4	2.8
15	28.7	4.1	28.7	15	28.7	4.1
20	29.9	5.3	29.9	20	29.9	5.3
25	30.7	6.1	30.7	25	30.7	6.1
30	32	7.4	32	30	32	7.4
35	32.4	7.8	32.4	35	32.4	7.8
40	33	8.4	33	40	33	8.4
45	33.7	9.1	33.7	45	33.7	9.1

#### 4. CONCLUSION

In view of the results, it can be concluded that the yarns studied are optimal to be used in the development of intelligent textiles, since they have a conductivity and resistivity that will allow them to provide possibilities to the fabrics. In cases where a yarn with higher resistivity and less conductivity is needed, the Bekinox VN 15/1X90 type could be used, which would be useful for using the Joule effect to increase the temperature of the fabric [19], [20]. If the objective is to conduct electricity to power an element, we should use one with a lower resistivity such as the Bekinox VN 8/1X275. Therefore, it is observed that in the market there are different possibilities of yarns depending on the needs to be satisfied. In view of the results of the Joule effect and that a sample of 200 ml of water can increase by up to 9 °C, they are filaments that can be used to build fabrics that have thermal characteristics or that the increase in temperature can produce certain changes in the textile, as could be in the use of thermochromic dyes. From the perspective of thermal comfort, the higher-resistivity yarns can be deployed as distributed heating elements in selected areas of a garment, while the lower-resistivity yarns can be used as conductive tracks to supply power to sensors, controllers or heating zones. This combination would allow the textile to regulate the local microclimate close to the body, compensate for heat losses in cold environments and reduce the need for bulky insulating layers, improving comfort and wearer mobility.



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