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Research Article

Heating and Conductive Properties of Fabrics Made of Metal Yarns

Nilşen Sünter Eroğlu[1,*], Suat Canoğlu[2], Sehvan Müge Yükseloğlu[2]

[1]Institute of Pure and Applied Science, Marmara University, İstanbul, Turkey
[2] Department of Textile Engineering, Faculty of Technology, Marmara University, İstanbul, Turkey

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Abstract: In this study, various single-ply and double-ply woven and knitted fabrics consist of stainless steel wires with different densities were produced and later these fabrics were measured for their electrical properties, heating behaviour and potential usage areas. For the woven fabrics which have double-ply conductive yarns, it was observed that as the density of the conductive wire increases the current flow increases within the fabric and the heating temperature gets higher. On the other hand, for the knitted fabrics that contain single ply conductive yarns have shown better conductivity and lower heating ability than the ply knitted fabrics. It is also thought that, because of the conductive yarns of the knitted structure continuing uninterruptedly through the fabric itself and may behave as it is on the whole surface. However, when heating behaviour was examined, the knitted fabrics have shown less heat resistance than the woven fabrics. Because of that, it will be an advantage in the applications to be used for heating purposes, it is therefore suggested to use preferably double-ply conductive yarn as weft in the woven structures. Similarly, in electrical conductivity applications, the use of single ply conductive yarn within the knitted fabrics is predicted to provide positive results.

Keywords: *Metal yarn, Conductive textiles, Electrical conductivity, Smart textiles, Stainless steel wire.*

Metal Tel İçeren Kumaşların Isınma Ve İletkenlik Özellikleri

Özet: Bu çalışmada, farklı sıklıklarda tek ve çift katlı, örme ve dokuma yapıda paslanmaz çelik tel içeren kumaş üretimi yapılmış, kumaş yapıları karşılaştırılarak kumaşların elektriksel özellikleri, ısınma davranışları ve potansiyel kullanım alanları incelenmiştir. Dokuma kumaşlar için, kumaş içerisinde çift katlı iletken iplik kullanımında, iletken tel yoğunluğu artmasıyla kumaş üzerinden geçen akımın arttığı ve ısınma sıcaklığının daha yüksek olduğu görülmüştür. Örme kumaşlarda ise, tek katlı iletken ipliklerden oluşan kumaşlarda daha iyi iletkenlik, daha düşük ısınma yeteneği görülmüştür. Ayrıca, örme yapısındaki iletken ipliklerin kesintisiz olarak devam etmesinden ve tüm yüzeyde etki gösterebilmesinden dolayı örme kumaşlar dokuma kumaşlara göre daha yüksek iletkenlik özelliğine sahip olduğu düşünülmektedir. Ancak ısınma davranışı incelendiğinde, örme kumaşlar dokuma kumaşlara göre daha az ısı dayanımı göstermiştir. Bu sebeple ısıtma amaçlı kullanılacak uygulamalarda, dokuma kumaş kullanılacaksa, atkı ipliği olarak kullanılan çift katlı iletken iplik tercih edilmesi avantaj sağlayacaktır. Benzer şekilde, elektriksel iletkenlik uygulamalarında, örme kumaş kullanımında, tek katlı iletken iplik seçilmesinin olumlu sonuçlar sağlayacağı öngörülmektedir.

Anahtar kelimeler: *Metal iplik, İletken tekstil, Elektriksel iletkenlik, Akıllı tekstil, Paslanmaz çelik tel.*

[*] Corresponding author.
E-mail address: nilseneroglu@halic.edu.tr (N. Sünter Eroğlu)

1. Introduction

The textile industry has been developing with the proliferation of technological developments and the functionalization of products day by day. Conductive textile products can detect environmental conditions, respond to the situation and provide necessary warning and control systems as a result of working together with material science, electronics, information technology and classical textile products. Smart fabrics and interactive textiles have grown at an average rate of 20% in the last decade. According to the British Chamber of Commerce, the value of market for smart fabric and interactive textiles was being about $299 million in 2009, the value rose to around $600 million in 2013. It was $4 billion in 2016 and $14 billion in 2017. Taking into account technological developments, it is aimed to double in the year 2020 and reach 30 billion dollars [1]. Electrical conductivity in textile structures which are the basic structure of smart textiles are obtained by use of metallic fiber in production, coating textiles with metal oxides, salts or conductive polymers and composing multi-filament structures.

In literature studies with yarns containing metal wires, different yarn and fabric production techniques were used and their structural properties were examined. In this section, the studies will be briefly mentioned. Yu et al. (2015) have studied metal composite yarns made of cross-section polyester (CSP) /antibacterial nylon (AN) /and stainless steel wires (SSW) and woven fabrics in their work. The polyester yarn has lower tensile strength and elongation than antibacterial nylon, so low strength results are obtained. It has been observed that the tensile strength values of fabrics produced from metal composite yarns are directly proportional to the yarns [2]. Bedeloglu (2013a) produced hybrid yarn composed of acrylic/stainless steel (SS) and cotton/acrylic/SS at different ratios and examined wire diameter, raw material, and production techniques. In the study, yarns were used in weft direction on a rapier weaving machine and different types of twill and plain hybrid fabrics were composed. It has been observed that thermal resistance of twill fabrics is higher than that of plain fabrics and fabrics containing stainless steel wire increase thermal resistance. Cotton/acrylic fabrics have better thermal conductivity than acrylic fabrics [3]. Sezgin (2012) produced cotton, cotton/acrylic plain, twill and satin fabrics using inox, silver, and copper conductive yarns. The resulting fabrics were subjected to current flow with a direct current (DC) power supply and the temperature changes in the fabrics were measured with a thermal camera. In the studies, it was found that the ability to withstand temperatures and high stresses in plain fabrics with a higher connection point gave better results than twill and satin fabrics [4]. In another study of Bedeloglu (2013b), produced polyacrylic single-ply and double-ply hybrid yarn with two different diameter stainless steel wires and fabricated six plain and 1x1 rib knitted hybrid fabric. The variations in electromagnetic shielding effectiveness as well as reflection, absorption, and transmission and in other physical properties of knitted hybrid fabrics were measured by considering the structure of the fabrics and the wire contents. Fabrics made of single-ply hybrid yarns showed lower surface resistivity and better conductivity results. Rib fabrics using two-folded hybrid yarns exhibit higher electromagnetic shielding properties as they have more metal wire content and abrasion and pilling resistance [5]. Orth &Rehmi [1] produced conductive yarn from copper and silk core yarns. The produced yarns have high strength, high heat resistance and ability to be sewn in industrial machines without being damaged during sewing and embroidery. Conductive yarns with this feature and interactive electronic textile products could get a result of successful production. Erdemli and Sarıçam (2015) used two different weave types as plain and 3/1 twill, using copper and hybrid yarns with stainless steel wire and examined the drape of the woven fabrics. It was found that the level of drape was lower in 3/1 twill fabrics than in plain fabrics, but the use of copper or stainless steel wire in hybrid yarns used in weft yarn did not affect the drape coefficient in both types of knitting [6]. In the study conducted by Cottet et al. [1], the copper threads had a diameter of 40 μm and were insulated with a polyesterimide coating. This yarn was used in woven plain fabrics and had different applications.

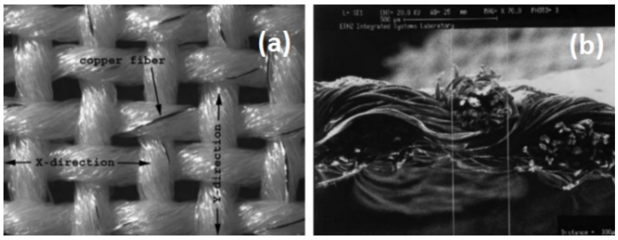

Figure 1. (a) Woven fabric with metal fibers and **(b)** fabric cross section [1].

In woven fabrics produced with conductive yarns, structures were built that consisted of network connections working analytically to increase product durability. Dhawan (2004) provided uniform conductivity effect at crossover point interconnects in fabrics. Zhang (2005) had produced a fabric having a high resistivity of stitching and exhibit high flexibility and comfort in a similar work for knitted fabrics. The conductive stitches in the fabric are produced by analytical equation [1].

In this study, single and double-layered, knitted and woven fabrics were produced at different density by using yarns containing stainless steel wire in different numbers. The electrical properties of the fabrics and the heating behaviour are mutually assessed with the fabrics. Thus, it is aimed to evaluate the potential applications of woven and knitted fabrics containing metal wires.

2. Experimental

2.1. Materials

In the experimental part, polyester conductive yarns containing 20 tex and 40 tex stainless steel wire were used in fabric production. The numbers and electrical conductivity values of the conductive composite yarns are given in Table 1. For the production of knitted fabrics, the fabric surface was formed by using conductive yarns containing metal wires as top thread, 7, 77 Tex lycra white yarn as bottom thread. Fabric surfaces are produced by Weihuan brand LT610 classic sock machine which works with 168 needles. Four different types of fabric were produced by changing the loop density settings of the machine (Table 2). For the production of woven fabrics, conductive yarns containing metal wires are used as the weft yarn, Ne 40/2 cotton yarn as warp yarn and fabric surface is formed in plain and twill woven at different warp/weft density. For plain fabrics, 8x27 model Kobsan brand narrow weaving machine was worked in 1400 rpm and 22-23°C. For twill fabrics, KKJ530 model Kus brand narrow weaving machine was used at 1400 rpm at 22-23°C (Table 3).

Table 1. Properties of conductive yarns.

Composition of Yarns	Linear Density		Electrical Conductivity
	Nm	Tex	
Stainless Steel/Polyester	50/1	20	40Ω/Cm (±20%)
Stainless Steel/Polyester	50/2	40	20Ω/Cm (±20%)

Table 2. Properties of knitted fabrics.

Fabric Code	Linear Density (Tex)	Course Density (Course/cm)	Inclination Angle * (°)
111	20	21	15
112	20	17	0,5
211	40	17	0
212	40	21	15

* Angle between platin and needle

Table 3. Properties of woven fabrics.

Fabric Code	Linear Density (Tex)	Weft Density (weft/cm)	Warp Density (warp/cm)	Fabric Structure
311	20	9,3	124	Plain
312	20	15,6	62	Twill
411	40	9,3	124	Plain
412	40	15,6	150	Twill

Knitted and woven fabrics were measured warming temperatures under 3V voltage. A double probe was used with a temperature gauge thermometer capable of measuring between -50°C and 110°C at 3 cm measurement distance (Figure 2). The relationships between yarn count, fabric structure, and fabric density were evaluated. This assessment is concerned with which areas of the fabric can be used functionally.

Figure 2. Temperature meter, sensor and measuring device

3. Results and Discussion

The results of measurements made with respect to the heating temperature are given in Figure 3.

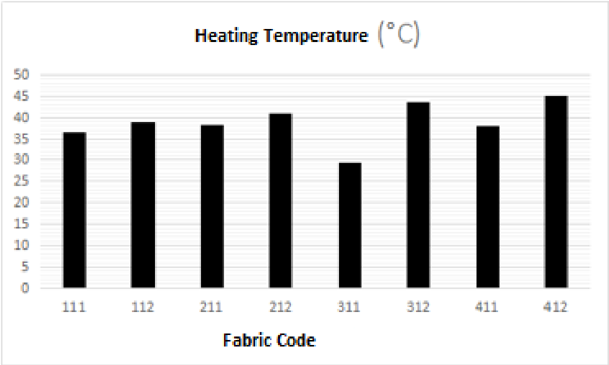

Figure 3. Warming temperatures of fabric under 3V voltage

During the measurements, the temperature change was expected to remain at a constant value, and the maximum value at which the constant was set was taken. Resistance measurement in multimeter with double probe for both the upper and lower surfaces of the fabric. 112, 311 and 411 were not measured completely. These measured values are in Table 4.

Table 4. Resistance values of fabrics.

Fabric Code	Resistance(Ω)
111	2,7
211	4,7
212	7
312	6,6
412	3,3

In this study, eight types of fabrics were produced considering the amount of conductive yarn in the fabric and the fabric density parameters and the heating temperatures and conductivity values were examined. As shown in Figure 3, the heating temperatures get higher as the amount of stainless-steel wire increases in the fabrics using double ply conductive. Warming temperature has also changed with the fabric structure (knitted or woven). Woven fabrics have been shown to provide warming up to higher temperatures. This is believed to be caused by the fact that the woven fabric construction is more rigid than the knitted fabric, thereby increasing the amount of current passing through the fabric. It has been observed that twill woven fabrics provide more heat than the plain fabrics. As a result, it can be predicted that woven fabrics produced with conductive yarns will provide more possibilities for use in heating applications than knitted fabrics.

When the conductivity values are examined, it has been found that woven fabrics produced with double-ply conductive yarns have lower electrical resistance value and therefore higher current flow capability than knitted fabrics. The fabric produced with double-ply conductive yarn has higher conductivity properties than single-ply conductive yarn due to the higher density of stainless-steel wire. For knitted fabrics, fabrics made of single-layer conductive yarns have a low resistance value and show high current passing capability. The result is that knitted fabrics generally exhibit better conductivity properties than woven fabrics. This difference is thought to arise from the fact that the continuous continuity of the conductive yarns in the knitted structure and its effect on the entire surface. In functional applications for conductivity, it will be beneficial to use double-ply conductive yarn on the woven fabrics. However, for the knitted fabrics a single-ply conductive yarn can be used.

4. Conclusion

In this study, for heating applications, it was observed that the selection of woven fabrics composed of double-ply conductive yarns used as weft yarns, and electrical conductivity applications, the selection of knitted fabrics composed of single-ply conductive yarns in would provide better results. The fabrics to be obtained are foreseen to be used in many applications which will facilitate our everyday life such as health applications, wireless communication, electromagnetic shielding. These textile structures, which consist of conductive components, will enable the design and manufacture of intelligent interactive products in today's market and are capable of addressing target population and problems.

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