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Research Article

Electrical Conductivity Investigation of Knitting Fabrics

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Abstract

Recently, using of electronic textiles have been investigated for many fields due to their various useage at electromagnetic shielding, biomedical devices, field-effect transistors, energy conversion and storage, etc. In this study, conductive fabrics were fabricated with using stainless steel yarn by knitting techniques. The knitted fabrics were produced four different constructions which are plain, garter stitch, 1x1 rib, and 2x2 rib knitting structure. After the knitting process, mass per unit area, loop yarn length, stitch density, thickness, porosity and conductivity of samples were analyzed. According to results, knitting parameters differ from fabric construction. Furthermore, fabric construction affects the porosity and electrical conductivity of samples. Plain knitting fabric sample has higher porosity than other samples. Compared with all knitting structures, electrical conductivity of 2x2 rib knitting fabric sample is higher than other fabric samples. This fabric can be used as electronic textile in electronic device.

Keywords: Stainless Steel Yarn, Knitting, Porosity, Electrical Conductivity.

Örme Kumaşların Elektrik İletkenliğinin Araştırılması

Öz

Son zamanlarda, elektronik tekstillerin kullanımı elektromagnetik kalkanlama, biyomedikal aletler, alan etkili transistörler, enerji dönüşümü ve depolama vb. gibi birçok alan için araştırılmaktadır. Bu çalışmada, iletken kumaşlar paslanmaz çelik iplik kullanılarak örme tekniği ile üretilmiştir. Örme kumaşlar düz, haroşe, 1x1 rip, ve 2x2 rip olmak üzere dört farklı konstriksüyonda üretilmiştir. Örme işleminden sonra numunelerin ilmek iplik uzunluğu, ilmek yoğunluğu, gramjı, kalınlığı, gözenekliliği ve iletkenliği belirlenmiştir. Elde edilen sonuçlara göre, örme parametreleri kumaş konstriksiyonuna göre değişiklik göstermektedir. Ayrıca, kumaş konstriksoyunu numunelerin gözenekliliğini ve elektrik iletkenliğini etkilemektedir. Düz örgü kumaş numunesi diğer numunelere göre daha yüksek gözenekliliğe sahiptir. Tüm örgü yapıları ile karşılaştırıldığında, 2x2 rib örgü kumaş numunesinin elektrik iletkenliği diğer kumaş numunelerinden daha yüksektir. Bu kumaş elektronik aletlerde elektronik tekstil olarak kullanılabilir.

Anahtar Kelimeler: Paslanmaz Çelik İplik, Örme, Gözeneklilik, Elektrik İletkenliği.

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1. Introduction

With the progress of new fibers, fabrics and innovative methods, the growth of textile industry has increased. In the late 1990s, it was began the researches on how to integrate conductive lines and circuits into the textiles. As results, textile materials have been become conductive and they are able to indicate curical changes in their mechanical or chemical properties, thermal, optical or electromagnetic properties. Among these functionalities, electrical conductivity is especially significant since it permits the incorporation of electronic or energy storage devices directly on the textiles (Tseghai et al., 2020; Salavagione et al., 2020; Trovato et al., 2020).

At the present time, electronic textiles have fascinated rising attention owing to their various useage in shielding materials, biomedical devices, field-effect transistors, energy conversion and storage, etc. (Kwon et al., 2015). Furthermore, interest in portable and electronic devices has increased and the growing attention leads to realize of electronic textiles. Electronic textiles (e-textiles) are identified as a textile material has electrical conductivity properties. In order to produce e-textiles, some techniques can be used which are adding metal particles to synthetic fibers in producing, using metal fibers and coating the textile surface with metal particles. Synthetic fibers such as polyester and nylon are produced with melt spinning method. Metal particles can be added to polymer solution in fiber production system. Metal yarns can be weaved or knitted with other fibers and electronic textile surface can be obtained (Weng et al., 2016).

In literature, there are various researches related to the use of conductive fabrics as sensor (Choi and Jiang, 2006; Soyaslan et al., 2010). In many research, the electromagnetic shielding effect of conductive fabrics was investigated (Hao et al., 2012). In addition, thermal fabrics used in medicine, insulation materials, health care, sports, air space, and outdoor activities can be produced with conductive yarns (Cheng et al., 2003). Conductive yarns can be manufactured from conductive metals which are stainless steel, ferrous alloys, titanium, silver, nickel, gold, aluminium and copper. Metal fibers are obtained as thin filaments, however, metallic conductive fibers are heavier, expensive, brittle and than many textile fibers.

Researchers have investigated electrical conductivity of textile surfaces produced from conductive yarn. Cheng et al. (2003) produced conductive yarn with using stainless steel core, kevlar and rayon shall. After, conductive fabrics were woven with the conductive yarn and electrical conductivities of fabric samples were investigated with regards to the weave construction. Kaynak et al. (2008) manufactured conductive cotton, wool, and naylon yarns with treated a continuous vapor polymerization method with polypyrrole. Oh et al. (2003) produced conductive fabrics with using in situ chemical polymerization of polypyrrole on nylon fabric. Jia et al. (2009) coated carbon fabric with silver nanowires using polyurethane and manufactured a highly electrically conductive fabric. Cui et al. (2015) added silver nanowires with fabrics by a dipping-drying method to produce conductive fabrics. The electrical resistivity of samples was obtained as 0.0047-0.0091 Ω. Meng et al. (2013) developed unique all-graphane core-sheath fibers composed of graphene fiber core with a sheath of 3D graphene network. Used as flexible electrodes, all-solid-state fiber supercapacitors were manufactured and can also be woven into a textile material for wearable electronics.

In this study, with use of stainless steel yarn, conductive fabrics were knitted. In the knitting process, four different techniques such as plain, garter stitch, 1x1 rib, 2x2 rib knitting were used and four different construction fabrics were obtained. After the knitting process, mass per unit area, loop yarn length, stich density, thickness, porosity, and conductivity of samples were determined. The results show that knitting parameters are differing from fabric construction. In addition, fabric construction affects the porosity and electrical conductivity of samples. Plain knitting fabric sample has higher porosity. Furthermore, 2x2 rib knitting fabric sample has higher electrical conductivity.

2. Material and Method

2.1. Yarn

In this study, stainless steel yarn was purchased from Technoart Company in Turkey. The specification of steel yarn was given in Table 1.

Table 1. Properties of Yarn

Fiber	Count (tex)	Fiber number	Diameter (mm)	Twist	Strength (KGF)
Stainless steel	325	150	12	Z	2.8

2.2. Preparation of Fabrics

All samples were manufactured using of 100% stainless steel yarn. Samples were knitted with four different techniques which are plain, garter stitch, 1x1 rib and 2x2 rib. The structure of fabric samples were given in Figure 1 (ISO, 1998).

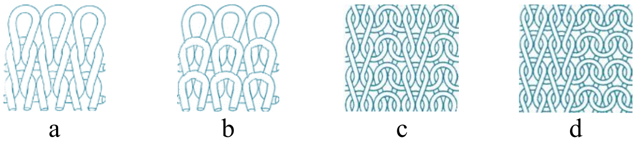

Figure 1. Knitting Structure of Fabric Samples (a. Plain knitting structure, b. Garter stitch knitting structure, c. 1x1 rib knitting structure, d. 2x2 rib knitting structure)

2.3. Loop Yarn Length

In order to obtain loop yarn length, each of the fabric samples were removed of 3 series included 30 loops and length of the removed yarn was measured. Afterworlds, the length value were divided to loop number.

2.4. Stitch Density

The number of loops in one square centimeter of fabric is measured using a magnifier. This measurement was repeated at five different places on each sample and the resulting values were averaged.

2.5. Mass Per Unit Area

First, 100 mm x 100 mm size from the fabric samples were prepared and weighted with an analytical balance in a standard atmosphere. Mass per unit area measurements of sample were iterated five times.

2.6. Thickness

The thickness of fabric samples was measured with James Heal Thickness Gauge. The measuring principle of thickness gauge is which measured of the distance between the reference plate of the device and parallel presser foot of the measuring device. The measurements of sample thickness were iterated five times.

2.7. Porosity

The porosity of fabric samples was calculated with Equation 1. In this equation, P is porosity of samples (%), A is area of sample (cm^2), W is weight of sample (g), T is thickness of the sample (cm), and D is density of yarn (g/cm^3). According to the Equation 1, fabric porosity effects weight and unit area of fabric (Tao, 2005).

$$P = \frac{100(AT - \frac{W}{D})}{AT} \qquad (1)$$

2.8. Conductivity Measurement

Electrical conductivity of samples were analyzed with using an Agilent 4339B high resistance meter (Agilent Technologies Co., Ltd., USA) at 65 % RH and 20°C, and the electrical conductivity of the samples were calculated according to Equation 2,

$$\sigma = \frac{L}{RxS} \qquad (2)$$

where σ is electrical conductivity (S/cm), R is electrical resistance (Ω), L is the length (cm) and S is the cross section area (cm^2) (Tao, 2005). The measurement setup is given in Figure 2.

Figure 2. Electrical Conductivity Measurement Setup

3. Results and Discussion

3.1. Fabric Parameters

The fabric parameters are given in Table 2. The fabric parameters which are loop yarn length, stitch density, thickness, and mass per unit area differ with regards to fabric construction.

3.2. Conductivity Results

The electrical resistivity values of samples were given in Table 3.

Table 3. Electrical Resistivity Value of Samples

Sample Code	Electrical resistivity (Ω)
Plain knitting	3,775
Garter stitch knitting	3,700
1x1 rib knitting	3.320
2x2 rib knitting	3.025

Electrical resistivity is affected the type of material, material construction, molecular structure and atomic configuration of material, total length, cross sectional area and temperature. Metals have high electrical conductivity since valance electrons are free form in metals. Ionic and covalent bonded materials have low electrical conductivity since they do not contain free electrons (Dias and Delkumburewatte, 2007). In this study, all fabric samples were produced from stainless steel yarn. For this reason, material type, molecular structure and atomic configuration factors are not affected from the electrical resistivity of samples. The electrical resistivity of samples is affected to material construction. Porosity, thickness, cover factor, yarn position and mass per unit area are known as factors of a fabric construction (Dias and Delkumburewatte, 2007). Electrical resistivity results show that plain knitting fabric has higher electrical resistivity compared with other samples. It was though that plain knitting fabric has higher porosity as a results has more air molecules than other knitting fabrics. As the electrical resistivity of air is much higher than that of steel, air increased the electrical resistivity of knitting fabrics comprising steel fibers. Due to the larger amount of air in steel knitted fabrics, the electrical resistivity of samples increased.

The effect of knitting construction on electrical conductivity values of the fabric samples, the electrical conductivity values of plain, garter stitch, 1x1 rib and 2x2 rib knitting fabric samples are given in Figure 3.

Table 2. The Fabric Parameters of Samples

Sample Code	Loop yarn length (mm)	Stitch density (number/cm^2)	Mass per unit area (g/cm^2)	Thickness (mm)
Plain knitting	1.125	20	0.118	3.07
Garter stitch knitting	1.400	16	0.130	3.30
1x1 rib knitting	1.600	12	0.146	4.58
2x2 rib knitting	1.625	12	0.162	3.83

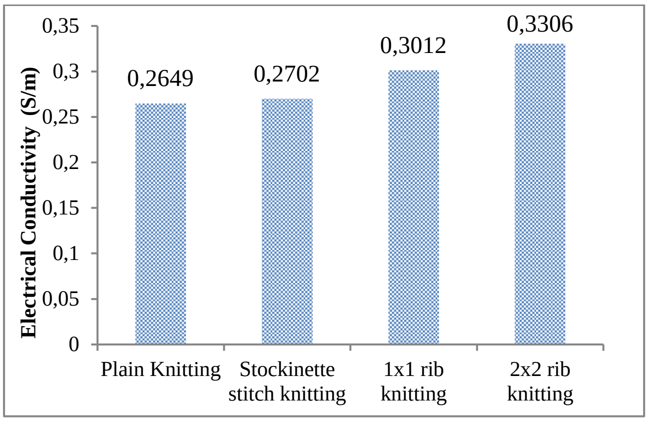

Figure 3. Electrical Conductivity Values of Knitting Fabric Samples

Compared with fabric constructions, 2x2 rib knitting has high electrical conductivity and plain knitting structure is thicker and lighter than other three knitting structures. Furthermore, porosity of plain knitting fabric is higher than other knitting fabrics. In the fabric samples, 2x2 rib knitting fabric sample has higher thickness and mass per unit area than other samples. It was thought that higher electrical conductivity value was obtained in 2x2 rib knitting fabric due to the fact that yarns can be packed closer because of higher number of interlacing in meter; therefore, the porosity of the fabric reduces and it results in higher electrical conductivity in 2x2 rib knitting fabric (Wong atl al., 2012). In the present study, 2x2 rib knitting fabric sample was found to have lower porosity than the other knitting fabrics. In addition, thickness affecting directly to the electrical conductivity of any material (Dias and Delkumburewatte, 2007), 2x2 rib knitting fabric sample has higher electrical conductivity due to higher thickness. The electrical conductivity of samples is proportional to the porosity. A fabric with higher porosity represents that the fabric structure encompasses more void spaces or fabric pores. In the pores of a fabric, there are air molecules and the electrical resistivity of air ranges from $10^9\Omega$ to $10^{15}\Omega$. In other words, air molecules in fabric causes an incresae in the electrical resistivity of fabric. Fabric construction is the major factor to determine the porosity of a fabric. Furthermore, the fabric construction influences the pore size, pore distribution, pore connectivity and total pore volume, and all these properties affect the porosity properties of a fabric (Marischal et al., 2018).

In literature, researchers have carried out many investigations related to electrical conductivity of different materials. In these studies, it was aimed to increase electrical conductivity of samples. In this regard, Table 4 shows the comparison of electrical conductivity of some materials and the sample having high electrical conductivity in this study. Compared with these materials, electrical conductivity of 2x2 rib knitting is median. Compared to other material, the electrical conductivity of 2x2 rib knitting is promising.

3.3. Porosity Results

The porosity values of samples are given in Table 5.

Table 5. The Porosity Values of Samples

Sample Code	Porosity (%)
Plain knitting	97.3
Garter stitch knitting	95.4
1x1 rib knitting	94.1
2x2 rib knitting	92.3

Among four knitted fabrics, the plain knitting construction has high porosity than garter stitch, 1x1 rib and 2x2 rib knitting structure, however, 2x2 rib knitting fabric has the lowest porosity. The reason could be deemed that the lower mass per square meter and thickness of plain fabrics causes. Furthermore, 2x2 rib knitting fabric has higher thickness and mass per square meter than other samples. According to the Equation 1, porosity varies according to density of yarn, area, weight and thickness of fabric.

4. Conclusion

The present work was undertaken with the objective of preparing electrical conductive knitting fabrics and studying their various properties which are loop yarn length, stich density, mass per unit area, thickness, porosity and electrical conductivity of samples. According to the results, knitting parameters vary from to fabric construction. It was obtained that plain knitting fabric sample has higher porosity than other samples. Compared with all knitting structures, 2x2 rib knitting fabric sample has the highest electrical conductivity. Furthermore, the study results show that porosity is thought to be major indicator for electrical conductivity of a fabric.

Table 4. Electrical Conductivity of Some Materials

Material	Electrical Conductivity (S/cm)
Carbone black filler filled polyamide 12 fibers (Cai et al. 2017)	10^{-4}
Cotton fabric coated with graphene oxide (Hong et al. 2016)	10^{-1}
Plain knitting produced from ultra high molecular weight polyethylene/polianiline composite yarn (Mengal et al. 2016)	0.087
Graphene oxide nanosheets (GONs) coated on to lyocell fabric (Fegutsu et al. 2007)	25
Polyester yarn dyed with carbon nanotube (Randeniya et al. 2010)	10^1
Cu-Carbone Nanotube (Fegutsu et al. 2010)	2x10^5
Au-Carbone Nanotube (Fegutsu et al. 2010)	3x10^5
Graphane-coloured fabric (Fegutsu et al. 2010)	0.0108
Combined silver nanowires with cupro fabrics (Cui et al. 2015)	109,89
2x2 rib knitting	**0.3306x10^2**

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