Filiz Sekerden

Effect of the Constructions of Metal Fabrics on their Electrical Resistance

Textile, Clothing, Footwear and Leather Department, Iskenderun Vocational Schools, Mustafa Kemal University,
Hatay, Turkey
E-mail: filizsekerden@yahoo.com

Abstract
In recent years, electrically conductive fabrics have been widely used in many fields such as medicine, sensors, sport, electrostatic discharge, electromagnetic interference (EMI) shielding and military applications. This study examines the effects of weft yarn types and weave types on the surface electrical resistivity and vertical electrical resistances of metal/cotton electrically conductive woven fabrics. Fabrics were produced using four different types of stainless steel/cotton weft yarns. Effects of weave type and weft yarn type on the electrical resistances of the fabrics were examined using analysis of variance (ANOVA). It was concluded that the weft yarn type and weave type significantly affect the surface electrical resistivity and vertical electrical resistance of the fabrics at a significance level of 0.05.

Key words: *metal fabric, steel yarn, surface electrical resistivity, vertical electrical resistance.*

Introduction

Conductive textile materials play a major role in the production of industrial products such as electromagnetic protection, prevention of dust and bacteria, static unloading, and sensors [1].

Conventional textile fabrics are poor electrical conductors [2]. There are many methods for imparting electrical conductivity to a textile fibre, yarn or fabric. The method used is determined by the specific requirements of the end product [3]. Some of the methods to obtain conductive fabrics are the use of fibres and yarns made from metals of steel, copper, aluminium and silver, as well as intrinsically conductive polymers, or metallic fillers or coatings incorporated in the yarn manufactured [4, 5]. Input and output devices, sensors, and power supplies are integrated into the fabrics by application or weaving [6].

In this study, yarn containing metal, one of the methods of producing conductive fabrics, is used. Conductive yarns are produced from metal fibres that have high electrical conductivity, such as stainless steel and copper [2, 3]. They are produced by mixing metal fibres with chemical, cotton and viscose fibres [4]; these increase the electrical conductivity of the fabric, thus eliminating electrostatic charges [5] and preventing static loading on the fabric [6]. Electrical properties of fabrics vary with the core material and diameter of the fibre [12]. Fabrics made from different fibre materials show different values of electrical resistance due to varying water absorption mechanisms and fibre specific areas [13].

Many researchers have worked on the electrical conductivity properties of conductive polymer coated fabrics [14-17]. Electrical conductivity is increased by raising the concentration of the organic polymer [17]. The structure of fabrics affects their electrical conductivity. The weave type and weft densities of fabrics coated with conductive polymer affect their surface resistivity, for example increased weft densities reduce the surface resistivities of fabrics. Moreover the surface resistivity of fabrics increase simultaneously with the number of warp and weft intersections [14]. Also the fibre type affects the surface resistivity of fabrics produced [15]. Some researchers have reported that surface electrical resistance depends on both the material and the geometry of electrodes used in the measurement [18].

A review of the literature revealed that previous studies mainly concentrated on electrical resistance properties of coated fabrics with conductive polymers. Enough studies about the effect of fabric parameters on the electrical resistivity properties of metal fabrics could not be found. The objective of this study wasto investigate the effect of weave types and weft yarn types on the surface electrical resistivity and vertical electrical resistances of conductive metal fabrics.

Materials and methods

Material

One type of warp yarn (14.76×2 tex PES/Vis+4.44 tex elastane) and four different types of weft yarns, including stainless steel, were used in the fabrics. Two different metal yarn diameters were used in the weft yarns: 316L stainless steel yarns of 50 and 35 μm. The steel yarns were plied with cotton yarns. The fabrics were produced with a Somet gripper weaving machine. ***Figure 1*** shows SEM images of the weft yarns used in the study, and the basic characteristics of the fabrics are given in ***Table 1***. For weft yarn types, subindex references 1 to 4 were used, the codes of which are presented in ***Table 1***, and are also used in ***Figure 1***, ***Figures 3 - 5***, ***Tables 6*** and ***9***.

Method

There are three types of electrical resistance: linear, surface and vertical electrical resistances [19]. The surface resistivity and vertical electrical resistances of metal/cotton fabrics were measured in the study. A Megger MIT520 Megohmmeter Insulation Resistance Tester was used to measure surface and volume electrical resistances (***Figure 2***).

Surface resistivity was calculated according to Standard TS EN 1149-1 [20]. Vertical electrical resistances of the fabrics were measured according to the TS EN 1149-2 standard [20]. Tests were conducted after the samples had been conditioned for 24 hours, as specified in the standard (23 ± 1 °C, 25 ± 5% relative humidity). Surface electrical resistance measurements were repeated at five different positions on the test sample, and the geometric mean of the results was calculated. ***Equations 1*** and ***2*** were used in the calculations. The value of the five measurements was calculated according to ***Equations 1*** , and then their geometric mean was determined [20].

ρ is the surface resistivity calculated in Ω, R the resistance measured in Ω, k the geometric factor of the electrode, (for the electrode used in the test, this factor equals $k = 19.8$) in ***Equations 1***, and the k factor is calculated using ***Equations 2***.

$$\rho = k \times R \qquad (1)$$

r_1 is the inner electrode diameter; $r_1 = 25.2$ mm and r_2 is the outer electrode diameter; $r_2 = 34.6$ mm in ***Equations 2.***

$$k = \frac{2\pi}{\log_e\left(\frac{r_2}{r_1}\right)} \qquad (2)$$

Vertical electrical resistance measurements were repeated at four different positions on four test samples, and the arithmetic mean of the measurements was calculated [21].

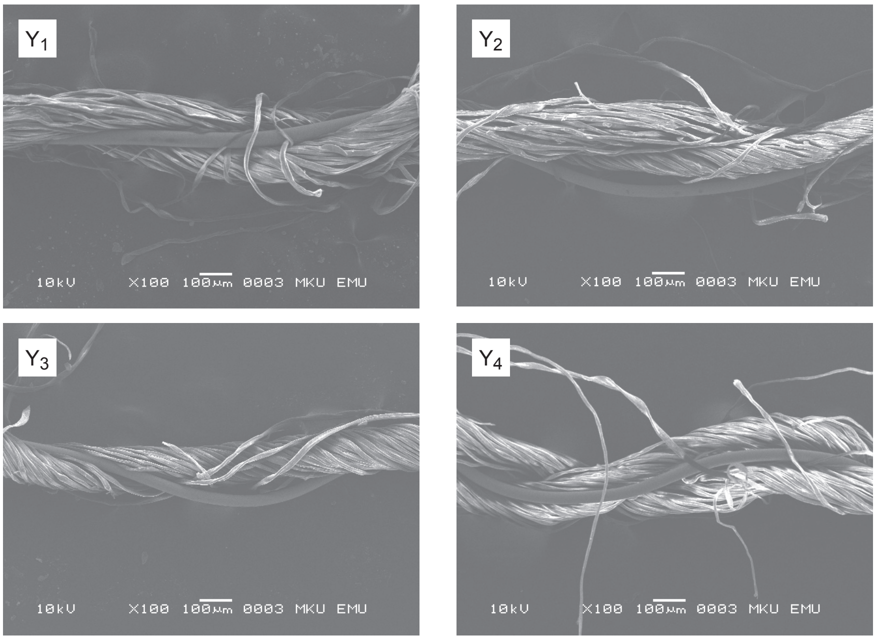


Figure 1. *Weft yarns used in the study.*

Figure 2. *Digital Ohmmeter (a) and electrodes (b).*

Statistical analysis

Two-factor analysis of variance (ANOVA) wasused to determine the relation-

Table 1. *Weave types of fabrics and weft yarns.*

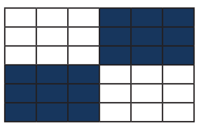
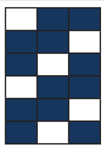
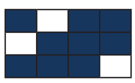
Yarn code	Weft yarn linear density, tex	Warp yarn linear density, tex	Diameter of stainless steel, µm	Weave pattern	Weave code	Surface mass, g/m²	Density (weft × warp), yarns/cm
Y_1	9.83 × 2	33.9	50	 Basket 3/3	B 3/3	401.39	28 × 33
Y_2			35			400.19	
Y_3	9.83					404.44	
Y_4	7.38 ×2					409.77	
Y_1	9.83×2		50	 Twill 2/1	T 2/1	332.61	
Y_2			35			317.32	
Y_3	9.83					317.19	
Y_4	7.38 ×2					312.94	
Y_1	9.83×2		50	 Twill 3/3 horizontal	T 3/3 H	437.10	
Y_2			35			421.68	
Y_3	9.83					447.67	
Y_4	7.38 ×2					452.96	

Table 2. Descriptions of the statistical terms.

Statistical term	Description
p-value	The term p-value is the probability that the results of the study are only due to chance. If the p-value is less than 0.05, it is considered statistically significant, and if the p-value is greater than 0.05, it is considered statistically not significant [22]. If the p-value of a variable is greater than 0.05, then the variable can be removed from the model.
R-squared	The term R-squared is the coefficient of determination. It expresses how much of the variance of the dependent variable measurements is explained by independent variables of the model [23]. Values of R-squared are between 0-1. A value of 0 indicates that the regression is not existent while a value of 1 shows an excellent linear relationship [24].
F value	The term F value, which is a statistic, is given in F-tables for different probability levels. If the F-value calculated in the Anova is greater than the value in the F- tables, the independent factor or interactions are expected to be significant at that probability or confidence limit [25].
Pure error	The pure error is that between observations (experiments) taken in the same treatment.
Mean Difference	The term is the mean difference between the group means

Table 3. Dependent and independent variables.

Dependent variable	Independent variable
S_R (Surface electrical resistivity)	Y_T (Yarn type)
V_R (Vertical electrical resistance)	W_T (Weave type)

ship between independent and dependent variables. Tukey's HSD (Honestly Significant Differences) post-hoc test was performed after the ANOVA test was completed in order to determine which groups differ from each other. A 0.05 level of significance was used in the statistical analysis.

A description of the statistical terms used in the tables is provided in ***Table 2***, dependent and independent variables are given in ***Table 3***.

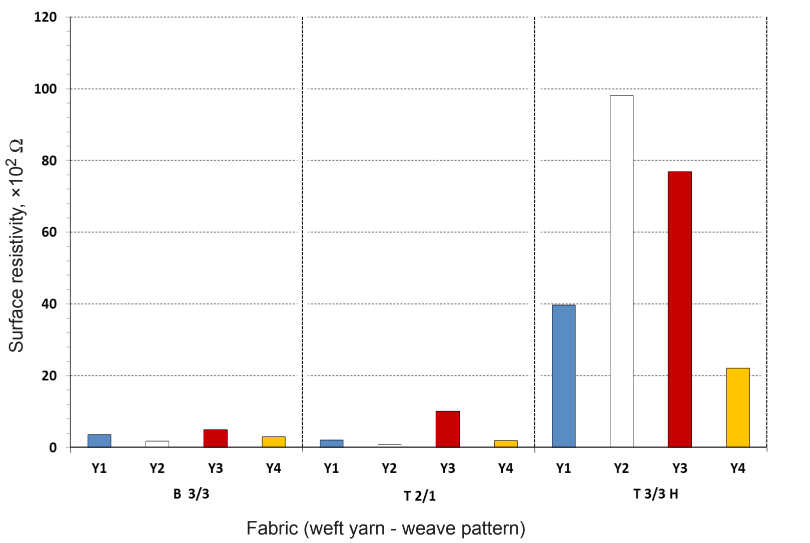


Figure 3. *Surface resistivity of the fabrics.*

Table 4. Results of surface resistivity (ANOVA).

Source	F value	p-value (Significance)	% contribution
Model	4620	< 0.0001	Significant
Y_T	1770	< 0.0001	8.02
W_T	17240	< 0.0001	67.79
Y_TW_T	2044	< 0.0001	24.11
Pure error			0.08
R-squared	0.9992		

Results and discussions

Surface electrical resistivity

Surface resistivity results calculated according to ***Equation 1*** are shown in ***Figure 3***; ANOVA results are given in ***Table 4***, and SEM images of the fabrics woven with Y_1 weft yarn in three different weave types are shown in ***Figure 4***.

Surface resistivities of the fabrics varied according to the weave type and weft metal yarn type, and the surface electrical resistivity of T 3/3 H is found to be higher than for the other weave types (***Figure 3***). According to ***Figure 4***, metal yarns are barely visible on the fabric surface of T 3/3 H, but are more visible in B 3/3 and T 2/1, which indicates that the measurement electrodes have less contact with the metal yarns in T 3/3 H, resulting in higher electrical resistivity measured. According to data in the literature, surface resistivity increases simultaneously with the number of warp and weft intersections [14]. The findings of the present study support this finding. Although the thicknesses of Y_1 and Y_2 yarn are the same, the metal yarn diameter in Y_1 is thicker than that in Y_2 (***Table 1***). And the cross-sectional area of Y_1 is higher than that of Y_2. For this reason, surface resistivities of woven fabrics produced using weft yarn Y_1 are expected to be lower than those of fabrics produced using weft yarn Y_2, because the resistance of any material is inversely proportional to its cross-sectional area [26, 27]. The result expected is seen only for weave type T 3/3 H (***Figure 3***). The thickness of Y_2 is higher than Y_3 because Y_2 is double ply yarn while Y_3 is single ply . The metal yarn diameter in Y_2 and Y_3 are same (***Table 1***). Surface resistivities of woven fabrics produced using weft yarn Y_2 are expected to be lower than those of fabrics produced using Y_3 weft yarn. The result expected is seen for the B 3/3 and T 2/2 weave types (***Figure 3***). The Y_2 and Y_4 weft yarns are both ply, with the thickness of Y_2 being higher than that of Y_4 and the metal yarn diameters in Y_2 and Y_4 being the same (***Table 1***). Surface resistivities of woven fabrics produced using weft yarn Y_2 are expected to be lower than those of fabrics produced using weft yarn Y_4. The result expected is seen for all of the weave types (***Figure 3***). As result of these, the settlement shape of the metal yarn in the fabric structure is thought to be as important as weft yarn thicknesses, metal yarn diameters in the weft yarns and also weave types. It is thought that the values of surface resistivity increased while increasing the distances between conductive metal yarns and when increasing the distances between electrodes and metal yarns.

The F-value of the model is 4620, which means that the model is significant. There is only a 0.01% chance that a "Model F-value" this large could occur due to noise. Values of p-value less than 0.05 indicate that the model terms are significant. In this case Y_T, W_T, Y_TW_T are significant model terms. The two-way ANOVA shows that Y_T, W_T and Y_T-W_T interactions have a statistically significant effect on the surface resistivity ($p < 0.0001$). Weave type has the greatest effect on surface resistivity (67.79%). The R-squared value of the model is 0.9992. In this case, the terms in the model can explain the model approximately 99 % (***Table 4***).

The significance values of Y_T and W_T are both less than 0.05, which shows that the terms are significant for the model. However, these results do not tell us which weave types or/and yarn types are responsible for the difference. Tukey's HSD (Honestly Significant Differences) post-hoc test was used in order to determine which groups differ from each other. At the end of the Tukey's HSD test for weave types, a significant difference was not observed between weave types B 3/3 and T 2/1 ($p = 0.997$). However, T 3/3 H is significantly different ($p < 0.001$) from types B 3/3 and T 2/1 (***Table 5***). As a result of the Tukey's HSD test for yarn types, a statistically significant difference was not found between the weft yarns (***Table 6***).

Table 5. *Tukey's HSD test for weave types (Surface electrical resistivity); *The mean difference is significant at the 0.05 level.*

	(I) weave type	(J) weave type	Mean difference (I - J)	p-value (Significance)
Tukey's HSD	B 3/3	T 2/1	-41.45	0.997
		T 3/3 H	-5524.21*	<0.001
	T 2/1	B 3/3	41.45	0.997
		T 3/3 H	-5482.76*	<0.001
	T 3/3 H	B 3/3	5524.21*	<0.001
		T 2/1	5482.76*	<0.001

Table 6. *Tukey's HSD test for yarn types (Surface electrical resistivity); *The mean difference is significant at the 0.05 level.*

	(I) yarn type	(J) yarn type	Mean difference (I - J)	p-value (Significance)
Tukey's HSD	Y_1	Y_2	-1692.04	0.427
		Y_3	-1327.84	0.630
		Y_4	706.24	0.919
	Y_2	Y_1	1692.04	0.427
		Y_3	364.20	0.988
		Y_4	2398.28	0.145
	Y_3	Y_1	1327.84	0.630
		Y_2	-364.20	0.988
		Y_4	2034.08	0.267
	Y_4	Y_1	-706.24	0.919
		Y_2	-2398.28	0.145
		Y_3	-2034.08	0.267

Vertical electrical resistance

Vertical resistance results of the fabrics are shown in ***Figure 5***, and ANOVA results are given in ***Table 7***. ***Table 8*** indicates the Tukey's HSD test for weave types and ***Table 9*** indicates the Tukey's HSD test for yarn types.

Vertical resistances of the fabrics varied according to weave type. The vertical resistance of T 3/3 H is found to be higher than the other weave types, as seen in ***Figure 5***, which may be caused by the long floats of weft yarns in T 3/3 H. The slipping and displacement of the weft yarns may have occurred in the T3/3 H weave type. The vertical resistance may have increased with the decrease in distances between metal/cotton weft yarns.

Although the thicknesses of the Y_1 and Y_2 yarn are the same, the metal yarn diameter in Y_1 is thicker than the metal yarn diameter in Y_2 (***Table 1***). And the cross-sectional area of Y_1 is higher than that of Y_2. For this reason, vertical resistances of the woven fabrics produced using weft yarn Y_1 is expected to be lower than the surface resistivities of fabrics produced using weft yarn Y_2. The result is expected seen for weave types T 2/1 and T 3/3 H (***Figure 5***). The thickness of Y_2 is higher than that of Y_3 because Y_2 is double ply yarn while Y_3 is single ply. The metal yarn diameter in Y_2 and Y_3 is the same (***Table 1***). The vertical resistances of woven fabrics produced using weft yarn Y_2 is expected to be lower than the surface vertical resistances of fabrics produced using weft yarn Y_3. The result expected is seen for all of the weave types (***Figure 5***). Weft yarns Y_2 and Y_4 are both double ply yarns, with the thickness of Y_2 being higher than that of Y_4 and the metal yarn diameters in Y_2 and

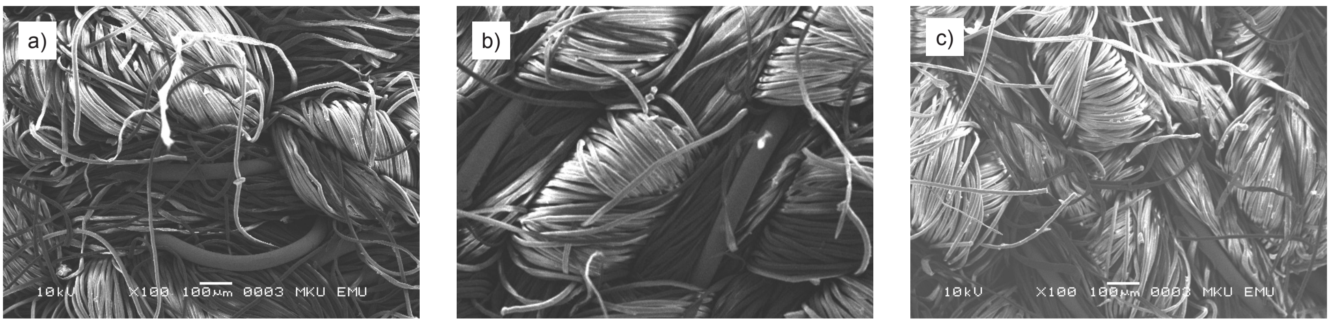


Figure 4. *Surface images of the fabrics (weft yarn: Y_1); a) B 3/3, b) T 2/1, c) T 3/3H .*

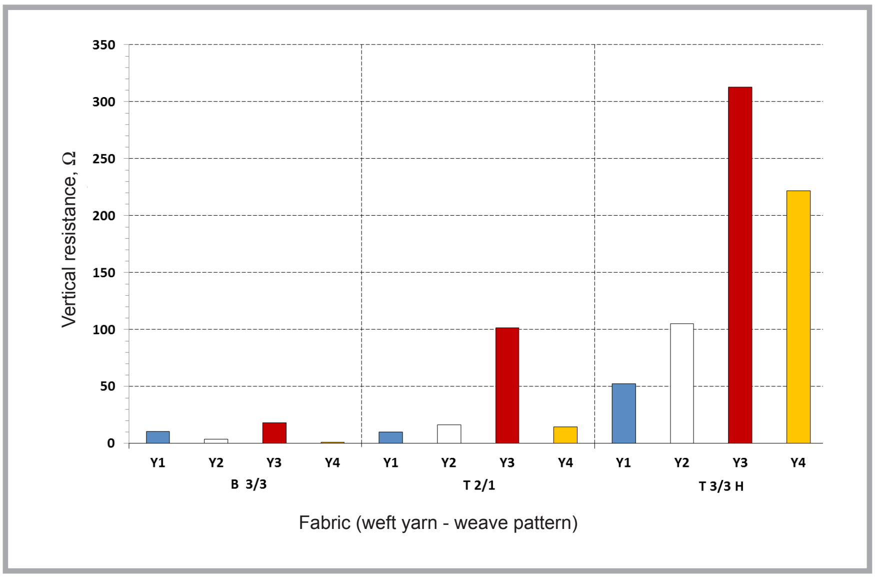


Figure 5. *Vertical resistance of the fabrics.*

Table 7. *Analysis of variance (ANOVA) test results of vertical resistance.*

Source	F value	p-value	% contribution
Model	5451	< 0.0001	Significant
Y_T	2931	< 0.0001	9.46
W_T	15780	< 0.0001	52.59
$Y_T W_T$	3789	< 0.0001	37.89
Pure error			0.06
R-squared	0.9993		

Table 8. *Tukey's HSD test for weave types (Vertical resistance); *The mean difference is significant at the 0.05 level.*

	(I) weave type	(J) weave type	Mean difference (I - J)	p-value (significance)
Tukey's HSD	B 3/3	T 2/1	-50.15*	0.029
		T 3/3 H	-154.85*	0.000
	T 2/1	B 3/3	50.15*	0.029
		T 3/3 H	-104.70*	0.000
	T 3/3 H	B 3/3	154.85*	0.000
		T 2/1	104.70*	0.000

Table 9. *Tukey's HSD test for yarn types (Vertical resistance); *The mean difference is significant at the 0.05 level*

	(I) yarn type	(J) yarn type	Mean difference (I - J)	p-value (significance)
Tukey's HSD	Y_1	Y_2	12.73	0.974
		Y_3	-80.47*	0.047
		Y_4	-19.33	0.918
	Y_2	Y_1	-12.73	0.974
		Y_3	-93.20*	0.016
		Y_4	-32.07	0.712
	Y_3	Y_1	80.47*	0.047
		Y_2	93.20*	0.016
		Y_4	61.13	0.189
	Y_4	Y_1	19.33	0.918
		Y_2	32.07	0.712
		Y_3	-61.13	0.189

Y_4 being the same (***Table 1***). The vertical resistances of woven fabrics produced using weft yarn Y_2 is expected to be lower than those of fabrics produced using weft yarn Y_4. The result expected is seen only for weave type T 3/3 H ***(Figure 5)***.

The F-value of the model is 5451, which means that the model is significant. There is only a 0.01% chance that a "Model F-value" this large could occur due to noise. Values of p-value less than 0.05 indicate that the model terms are significant. In this case Y_T, W_T, $Y_T W_T$ are significant model terms. The R-Squared value of the model is 0.9993. In this case, the terms in the model can explain the model approximately 99 % (***Table** 7*).

The two-way ANOVA results showed that the Y_T, W_T and Y_T-W_T interactions have a statistically significant effect on vertical resistance ($p < 0.0001$). However, weave type has the greatest effect on vertical resistance - 52.59% ***(Table** 7*).

The significance values of Y_T and W_T are both less than 0.05, which shows that the terms are significant for the model. However, these results do not tell us which weave types and/or yarn types are responsible for the difference. Tukey's HSD (Honestly Significant Differences) post-hoc test was used in order to determine which groups differ from each other. As a result of the Tukey's HSD test for weave types, a statistically significant difference was observed between weave types B 3/3, T 2/1 and T 3/3 H ($p<0.05$) (***Table 8***). As a result of the Tukey's HSD test for yarn types, a statistically significant difference wasfound between the Y_1 & Y_3 and Y_2 & Y_3 weft yarns (***Table 9***).

Conclusion

As a result of the present study, weave type and weft yarn type are determined to be significant factors affecting the surface electrical resistivities and vertical electrical resistances of conductive fabrics, with the most significant factor being weave type.

It may be indicated that the settlement shape of the metal yarn in the fabric structure is thought to be as important as weft yarn thicknesses, metal yarn diameters in the weft yarns and also weave type.

It is concluded that the distance between the electrode and metal yarns is very important. The values of surface resistivity and vertical resistance increase while increasing the distances between conductive metal yarns. Moreover the values also increase when increasing the distances between electrodes and metal yarns. The slipping and displacement of the conductive metal yarns may have influenced the results of electrical measurement.

Acknowledgements

I would like to extend my gratitude to Fibreinoks A.S. for providing weft yarns containing metal yarns, to MENSA A.S. for weaving the fabrics, to the Turkish Standart Enstitute (TSE) Ankara Electric Laboratory for making it possible to carry out the fabric tests in their laboratory, and to the Central Research Laboratory at Mustafa Kemal University Institute of Science for the SEM photographs of the fabrics

References

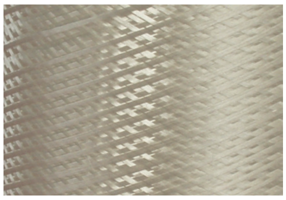
1. Bedeloglu Çelik A, Sünter N, Bozkurt Y. Electrically Conductive Textiles, Production Methods and Usage Areas. *Tekstil ve Mühendis* 2010; 79: 7-17.
2. Palamutcu S, Dağ N. Functional Textiles I: Electromagnetic Shielding Purposed Textile Surfaces. *Electronic Journal of Textile Technologies* 2009; 3, 1: 87-101.
3. Anderson K, Seyam AM. The Road to true Wearable Electronics. JTATM 2002; 2, 2: 1-20.
4. Bonaldi RR, Siores E, Shah T. Electromagnetic Shielding Characterisation of Several Conductive Fabrics for Medical Applications. *Journal of Fiber Bioengineering and Informatics* 2010; 2, 4: 237-245.
5. Rocha AM. *Development of Textile Based High Tech Products: The New Challenge*. *Wearable E-Health Systems For Personalised Health Management*. Editors: Lymeis, A., Rossi, D., IOS Press: 330-334, 2004.
6. Cheng IC, Wagner S. *Overwiew of flexible electronics Technology***.** Eds. Wong WS, Salleo A. Electronic Materials: Science & Technology- Flexible Electronics: Materials and Applications Springer, 200.
7. Kiekens P, Jayaraman S. *Intelligent Textiles and Cloting for Ballistic and NBC Protection*, 2011.
8. Jones R. The future of nanotechnology. *Physics World* 2004; 17, 8: 25-29.
9. http://www.ht-metalfiber.com/en/product/content_8767.html (accessed 17.05.2012).
10. Anonymous, 2011. Processing and finishing of Polymeric Materials, John Wiley & Sons Inc (2), 1488 pages.
11. Desai AA. Metallic fibres. http://www.fibre2fashion.com/industry-article/3/213/metallic-fibres13.asp, 18 pages (accessed 08.04.2012).
12. Weber W, Rabaey JM, Aarts EHL. Ambient Intelligence. Springer, 375 pages 2005.
13. Wang X, Xu W, Li W, Cui W. Study on the Electrical Resistance of Textiles under Wet Condition. 2009 79: 753-760.
14. Neelakandan R, Madhusoothanan M. Electrical Resistivity Studies on Polyaniline Coated Polyester Fabrics. *Journal of Engineered Fibers and Fabrics* 2010; 5, 3: 25-29.
15. Kumar NM, Thilagavathi G. Development and characterization of electrically conductive polyaniline coated fabrics. *Indian Journal of Chemical* 2012: 434-441.
16. Varesano A, Tonin C. Improving Electrical Performances of Wool Textiles: Synthesis of Conducting Polypyrrole on the Fiber Surface. 2011; 78, 12:110-115.
17. Abbasi AMR, Mangat MM, Baheti V, Militky J. Thermal Properties of Cotton Fabric Coated with Polypyrrole. *Journal of Bioengineering & Informatics* 2012; 5, 2: 163-168.
18. Gutiérrez M, Li H, Patton J. *Thin Film Surface Resistivity. In partial fulfillment of course requirements for Mate210 Experimental Methods in Materials Engineering*. 2002, 24pages,http://www.sjsu.edu./faculty/selvaduray/page/papers/mate210/thinfilm.pdf.
19. Liu K, Sun Y, Zhou R, Zhu H, Wang J, Lu L, Fan S, Jiany K. Carbon nanotube yarns with high tensile strength made by a twisting shrinking method. *Nanotechnology* 2010; 21: 1-7.
20. *Protective clothing - Electrostatic properties - Part 1: Test method for measurement of surface resistivity*. Turkish Standard Institute, 13 pages. TS EN 1149-1 , 1999.
21. *Protective clothing - Electrostatic properties - Part 2: Test method for measurement of the electrical resistance through a material (vertical resistance).* Turkish Standard Institute, 9 pages. TS EN 1149-2, 2000.
22. Glasziou PP, Del Mar C, Salisbury J. *Evidence Based Practice Workbook*. 2nd Ed., Blackwell Publishing, 202 pages, 2009.
23. Velten K. *Mathematical Modeling and Simulation*. Wiley-VCH, 348 pages, 2009.
24. Freund RJ, Wilson WJ, Sa P. *Regression Analysis- Statistical Modeling of a Response Variable*. 2nd Ed., Elsevier, 459 pages, 2006.
25. Giles HF Jr., Wagner JR Jr., Mount EM. III. Extrusion: *The Definitive Processing Guide and Handbook*. 3rd Ed. William Andrew Inc., 542 pages, 2007.
26. Anonymous. "Electrical Magnetic Properties of Metals". ASM International Materials Properties Database Committee, 2000; 285 pages.
27. Boctor SA. "Electric Circuit Analysis", Prentice-Hall 1987; 847 pages.

Received 27.09.2012 Reviewed 28.04.2013

Institute of Biopolymers and Chemical Fibres

Multifilament Chitosan Yarn

The Institute of Bioploymers and Chemical Fibres is in possession of the know- how and equipment to start the production of continuous chitosan fibres on an extended lab scale. The Institute is highly experienced in the wet – spinning of polysaccharides, especially chitosan. The Fibres from Natural Polymers department, run by Dr Dariusz Wawro, has elaborated a proprietary environmently-friendly method of producing continuous chitosan fibres with bobbins wound on in a form suitable for textile processing and medical application.



Multifilament chitosan yarn

We are ready, in cooperation with our customers, to conduct investigations aimed at the preparation of staple and continuous chitosan fibres tailored to specific needs in preparing non-woven and knit fabrics.

We presently offer a number of chitosan yarns with a variety of mechanical properties, and with single filaments in the range of 3.0 to 6.0 dtex.

The fibres offer new potential uses in medical products like dressing, implants and cell growth media.

For more information please contact:
Dariusz Wawro Ph.D., D. Sc., Eng
Instytut Biopolimerów i Włókien Chemicznych
ul. Skłodowskiej-Curie 19/27;
90-570 Łódź, Poland;
Phone: (48-42) 638-03-68, Fax: (48-42) 637-65-01
E-mail: dariusz.wawro@ibwch.lodz.pl