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THE ELECTRICAL AND PHYSICAL EFFECTS OF YARNS CONTAINING METAL WIRE ON KNITTED FABRIC

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Abstract: *The textile industry is developed with the proliferation of technological developments and the functionalization of products about conductive textile structures day by day. Many applications could be seen including metal yarns and knitted or woven fabrics containing metal wire. This paper reported analyze that fabrication method, physical, electrical and electromagnetic shielding (EMSE) properties for knitted fabrics with single and double folded yarn, which has stainless steel wire. Polyester /Stainless steel wire (80/20) yarns were used in single (Nm 50/1) and double (Nm 50/2) folded structure. These yarns were produced as single jersey knitted fabric in sock machine. The fabric structures were formed by using conductive yarns containing metal wires as upper yarn, 70/20 denier lycra white yarn as lower yarn. The physical properties including tensile, twist, and evenness of metal yarns were analyzed. The properties such as pilling, abrasion, conductivity, EMSE of single jersey knitted fabrics were measured. Knitted fabric with double folded yarns was better pilling, abrasion, EMSE, surface, and volume resistivity values compared to fabric containing single folded yarns. The density of metal yarn in knitted fabrics was directly effective on the pilling, abrasion, conductivity and EMSE results. Knitted fabric with double folded yarns was appropriate to structure for using in EMSE applications and electronic textiles.*

Key words: *Metal Yarn, Stainless Steel Wire, Conductivity, Electromagnetic Shielding Effectiveness*

1. INTRODUCTION

In recent years, conductive textile structures have been shown in a lot of applications such as industry, military, space, medicine, protection, communication, or automation. Some researchers, in previous studies, [1-6] manufactured and analyzed metal yarns and knitted or woven fabrics containing metal wire because of using in conductivity or electromagnetic shielding effectiveness (EMSE) areas. These studies show that yarns and knitted containing metal wire for using in conductive textiles have a great potential to develop in both scientific and industrial research areas.

The first primary objective of this research was produced knitted fabric composed of yarn containing stainless steel wire. The second objective of the research was analyzed some properties of metal yarns and physical, conductivity and EMSE properties for knitted fabrics with single and double folded yarn. A1 (Nm50/2), which is double folded yarn, and B1 (Nm 50/1), which is single folded yarn, were used as upper yarn and 70/20 denier lycra white yarn as lower yarn. The data obtained from the measurements are evaluated with the fabric structures and their relations with each other. The results were expected to guide for applying optimum metal fabric properties for using conductive textiles.

2. MATERIAL AND METHOD

2.1. Manufacturing of Knitted Fabrics

In the experimental part, polyester conductive yarns containing Nm50/2 (A) and Nm 50/1 (B) 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 single jersey knitted fabrics, the fabric surface was formed by using conductive yarns containing metal wires as upper yarn, 70/20 denier lycra white yarn as lower yarn. The fabric surfaces were produced by 168 needle-punched, LT610 classic sock machine of Weihuan brand. Two types of fabric were produced by changing the frequency settings of the machine (Table 2).

Table 1. *Properties of Conductive Yarns*

Composition of Yarns	Yarn Count		Electrical Conductivity*
	Nm	Dtex	
Stainless Steel/Polyester	50/1	200	40Ω/cm (±20%)
Stainless Steel/Polyester	50/2	400	20Ω/cm (±20%)

*Measured distance between electrodes = 5 cm

Table 2. *Properties of Single Jersey Knitted Fabrics*

Fabric Code	Yarn Number (Nm)	Weft Density (threads/cm)	Knitted Gauge * (°)
A1	50/2	17	0
B1	50/1	17	0,5

* Angle between platinum and needle

2.2. Measurements of Metal Yarns

The Tensile Strength of metal yarns was measured with Instron 4411 Tensile Strength Tester, Table Model (Metric) TM-M. The distance between the jaws was 10cm/min. Tenacity at Maximum load (cN/tex) is tensile strength of the yarn during breaking with the yarn pulling of the lower jaw. Elongation (%) is ratio of the first length of the yarn amount of elongation until the yarn breaking. Measurement of these values gives information about yarn strength.

The physical movement that allows the fiber to be joined is called a twist. The twisting tightens the fibers and provides a more adhering surface, preventing them from slipping over each other and providing yarn production. The number of yarn twists was measured by JAMES H. Heal& Co Twist tester according to TS 245 standard.

For subjective eveness method, the yarns were wrapped in a smooth and parallel manner on a black sheet. Standard photos were taken under appropriate light to obtain information about the yarn. Errors on thread periodic fluctuations and deformations were evaluated to the grade scale (A is better & D is worst) by ASTM Spun Yarn Appearance Standards.

2.3. Measurements of Knitted Fabrics

Abrasion (ASTM 4966) and pilling resistance (ASTM D4970) measurements of fabrics were evaluated with a Nu- Martindale Pilling and Abrasion Tester. Pilling resistance grades were interpreted according to EMPA Standard, SN 198525, K1 (1 is being poor & 5 is being excellent).

Conductivity measurements were performed on the knitted fabrics by using Keithley 6517A Electrometer High Resistance Meter instrument according to standard ASTM D257. Surface resistivity (ρs, ohm), Volume resistivity (ρv, ohm.cm) and Conductivity (σ, 1/ohm.cm) can be expressed as the following equations: [7]

$$\rho_v = R(\Omega) \times RCF \times t(cm) \quad (1)$$

$$\rho_s = R(\Omega) \times RCF \quad (2)$$

$$\sigma = 1/\rho_v \quad (3)$$

RCF (resistivity correction factor of the fabrics) is 53, 4 V and t (cm) is expressed that fabric thickness.

EMSE values are evaluated by general using such as casual wear, uniforms, and consumer electronic products in Table 2 [8]. EMSE (decibel, dB) of fabrics was measured by Electro-Metrics, Inc., model EM-2107A with ASTM D 4935-10 coaxial transmission line standard method ZVL Network Analyzer instrument between 0 and 3000 MHz.

Table 2: *Shielding Effectiveness (SE) Values of General Use*

Grading	Excellent	Very Good	Good	Moderate	Fair
Range	SE＞30 dB	30 dB≧SE ＞20 dB	20 dB≧SE ＞10 dB	10 dB≧SE ＞7 dB	7 dB≧SE ＞5 dB

The surface a views of metal yarns and knitted fabrics were obtained by using stereo microscopy. Metal yarns were viewed with 40 x magnification and knitted fabrics were as viewed front and back surface.

3. RESULTS AND DISCUSION

3.1. Metal Yarn Results

Metal yarn structures were viewed by stereo microscopy (see in Figure 1).The stainless steel wire was wrapped and seen clearly into the yarns.

Fig. 1: *Image of A1 and B1 yarns*

Table 3. *Tensile Properties of Metal Yarns*

Yarn Codes	Maximum Load (cN)	Elongation (%)	Tenacity at Maximum Load (cN/tex)	Extension at Maximum Load (mm)
A1	1142,90	12,81	29,11	32,01
B1	503,30	12,28	25,57	30,69

Tensile test results show that (in Table 3), in both yarn types, increasing yarn count or thinning of yarn was affected by decreasing strength and elongation (tensile strain at maximum load). The number of fiber and the amount of metal wire in yarn cross-section decreased with yarn thinning. In this case, fiber/ fiber and fiber / metal wire frictions, which directly affect strength and elongation, were reduced.

Table 4. *Twist and Evenness Properties of Yarns*

Yarn Codes	**Yarn Twist Amount (T/m)**	**Evenness (grade scale)**
A1	Z754,36	B
B1	S293,8	B

Increasing of the twist coefficient had increased tensile strength and elongation values because fibers and metal wires were better wrapped on each other. Increasing the twist is expected the result to increase the strength and elongation values.

Periodic fluctuations and deformations on the black plate were not numerous and neps in several places. According to this result, it was concluded that there is irregularity at the B level. B is stated in small quantities evenness for grade scale.

4.2. Knitted Fabric Results

Surface morphology of knitted fabrics were viewed by stereo microscopy (see in Figure 2). The A1 fabric, which is thicker with double folded yarn, was seen more frequent structure in fabric surface.

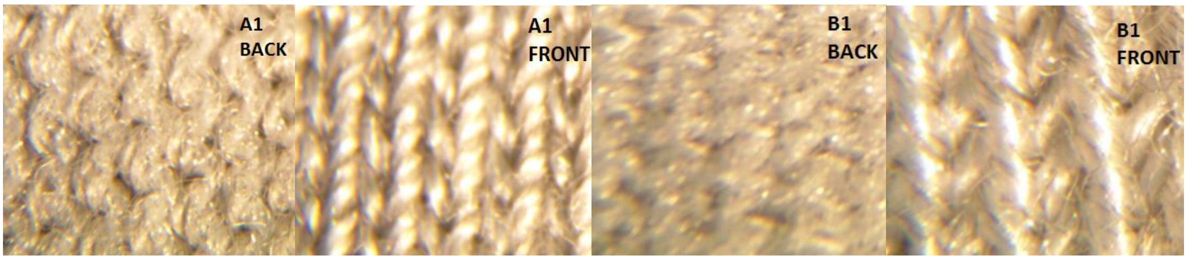

Fig 2: *Back and front of A1 and B1 Fabric Surfaces*

Table 5. *Pilling Grades of Knitted Fabrics*

Fabric Codes	Grades*
A1	1
B1	2

** According to EMPA Standard SN 198525, K1*

Pilling is due to the effect of friction forces on the fabric surface of the fiber ends and thus disrupts the fabric image. Almost every stage of textile production has an effect on pilling. The properties of the fiber used as raw materials, yarn properties, fabric properties and finally applied finishing processes are effective on pilling [9]. According to Table 5, A1 fabric, which is knitted with double folded yarn, has higher pilling resistance compared to B1 because of high cohesion force of fabric.

Table 6. *Abrasion Resistance Results of Knitted Fabrics*

Fabric Codes	Speed*
A1	175216
B1	195216

**Number of Revolutions at the time of Breaking*

The number of revolutions at the time of breaking of a loop in fabrics was measured. Yarns with high twist level is abraded less than yarns with low twist level [10]. Since the A1 yarn has a higher twist, it has been observed that the abrasion on the fabric surface is less than the B1 fabric (see in Table 6).

Table 7. *Conductivity Results of Fabrics*

Fabric Codes	Thickness (cm)	Surface resistivity (ρs, ohm)	Volume resistivity (ρv, ohm.cm)	Conductivity (σ, 1/ohm.cm)
A1	0,124	5,19582E+05	6,44281E+03	1,5521E-04
B1	0,119	2,2161E+04	2,63715E+03	0,3792E-03

Electric resistivity (ρ) is a measurement of the difficulty of wire against electric current. The low resistance indicates that the movement of the electric current is easily permissible [11]. Electric current flow is inversely correlated with the electrical volume resistivity and surface resistivity. Table 7 shows that B1 had higher conductivity results and lower surface and volume resistivity. Use of double folded yarn in the fabric increased surface and volume resistivity.

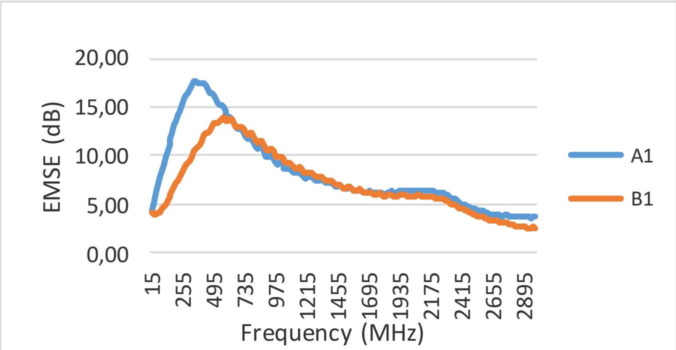

Fig.3: *EM Shielding Effectiveness of Fabrics*

The figure 3 showed that the best shielding and EMSE measurement results in fabrics the frequency ranges of 330-435MHz in A1 and 495-660MHz in B1. All of the fabrics had moderate grades for shielding effectiveness (dB) and the percentage of electromagnetic shielding (%).

EMSE values will increase by increasing the amount of stainless steel in the unit area per fabric [12]. The fabric, which was thinner with single folded yarn, displayed lower EMSE values as compared to double folded yarn. It was thought that this situation is due to the high density of wire in the double layer fabric.

5. CONCLUSION

In this study, polyester/stainless steel wire-based knitted fabrics with single and double folded yarns were successfully manufactured. It was seen to effects on pilling, abrasion, conductivity and EMSE of the fabric structure. Knitted fabric with double folded yarn (A1) has better pilling and abrasion resistance to B1 because of high cohesion force of fabric and high twist in A1 metal yarn. B1 fabric has a lower surface and volume resistivity because of low resistance electric current. A1 fabric displays better EMSE values because of the high density of wire structure. Amount of metal yarn in knitted fabrics was effective on the pilling, abrasion, conductivity and EMSE results.

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