Effect of washing and temperature on electrical properties of conductive yarns and woven fabrics

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ABSTRACT – REZUMAT

Effect of washing and temperature on electrical properties of conductive yarns and woven fabrics

In our daily life, the temperature and washing parameters go unnoticed on the electrical properties of conductive yarns and woven fabrics. However, in many cases, these parameters play a crucial role in the use of conductive materials since they modify their electrical properties. It is critical to predict what this behaviour will be, as these washing and, in our temperature, parameters can improve or even deteriorate desirable properties in the materials, especially of sensors embedded textiles. The weight of the conductive samples was decreased up to 11% for silver-coated and 7.75% for gold-coated yarn after washing. The results suggest that the electrical resistance of yarns increases 1.6%, 8%, and 8.7% for silver-coated while 13%, 20%, and 21% increase in resistance value for gold-coated yarn after 1st, 2nd, and 3rd wash, respectively. The silver-coated yarn has better electrical conductance, and ageing does not affect the electrical resistance of both silver-coated yarns and fabrics till two washes and a slight change occurred after 3rd wash. The woven structure's mass per unit area decreases up to 7.69% and 3.7% for silver-coated and gold-coated samples, respectively. Woven samples conductivity for silver-coated structures decreased 95% and 98% for gold-coated structures.

Keywords: *conductive yarns, woven structures, electrical resistance, ageing, conductive textiles*

Influența ciclurilor de spălare și a temperaturii asupra proprietăților electrice ale firelor și țesăturilor conductive

În viața noastră de zi cu zi, temperatura și parametrii de spălare trec neobservați în ceea ce privește proprietățile electrice ale firelor și țesăturilor conductive. Cu toate acestea, în multe cazuri, acești parametri joacă un rol crucial în utilizarea materialelor conductive, deoarece modifică proprietățile electrice. Este esențial să preconizăm care va fi acest comportament, deoarece aceste spălări și la temperatura stabilită, pot îmbunătăți sau chiar deteriora proprietățile dorite ale materialelor, în special ale textilelor cu senzori integrați. După spălare, greutatea probelor conductive a fost redusă până la 11% pentru firele acoperite cu argint și 7,75% pentru firele acoperite cu aur. Rezultatele sugerează că rezistența electrică a firelor crește cu 1,6%, 8% și 8,7% pentru cele acoperite cu argint, în timp ce valoarea rezistenței pentru firele acoperite cu aur crește cu 13%, 20% și 21% după prima, a doua și a treia spălare. Firul acoperit cu argint are o conductanță electrică mai bună, iar îmbătrânirea nu afectează rezistența electrică atât a firelor cât și a țesăturilor acoperite cu argint, până la două spălări, iar după a treia spălare a avut loc o ușoară modificare. Masa structurii țesute per unitatea de suprafață scade până la 7,69% și, respectiv, 3,7% pentru probele acoperite cu argint și respectiv cu aur. Conductivitatea probelor țesute pentru structurile acoperite cu argint a scăzut cu 95% și 98% pentru structurile acoperite cu aur.

***Cuvinte-cheie**: fire conductive, structuri țesute, rezistență electrică, îmbătrânire, textile conductive*

INTRODUCTION

Smart textiles or e-textiles are fibres, yarns, or fabrics that enable digital components such as batteries, light, and electronics to embed in them. Smart materials add a function to the textiles called e-textiles. This idea was generated in Japan for the first time in 1989. These are those categories of textiles having the ability to sense a change in environment and respond to them in a designed manner. This change in environment and the response both are electrical, thermal, chemical, or other bases. Smart textiles have extensive applications in the field of clothing. Smart clothing conveys, transmits, and drives the signals from one part of a structure into the other. Smart textiles are intelligent textiles that can sense and react to environmental stimuli. E-textile system is fabricated by the development of electrical devices like sensors, energy harvesting, actuators, storage items, etc. [1]. Smart textiles interact with the environment and such e-textiles are existing in different shapes and compositions (woven, knitted, or non-woven) [2]. The term e-textiles representing the class of fabric structures that sense and respond to environmental changes and multifaceted surroundings for e-textiles is shown in figure 1.

Wet spinning and melt spinnings are the processes/methods of fibre preparation which is electrically conductive [4]. The type of materials, fibre configuration, and fibre arrangement are the main factors for determining the performance of smart textiles [5].

Textiles "Smart Clothing"	Electrical Engineering "Wearable Electronics'	Information Science "Wearable Computer"

Fig. 1. Multifaceted surroundings for smart textiles [3]

Conductive fibres may also have electrical as well as delivering good antimicrobial, anti-static, and electromagnetic shielding properties [6]. Conducting polymers/fibres made from the thermosetting materials (non-thermoplastic) at low temperatures, such as fibres degrade and cannot be remelted or reused. A materials/fibres electrical conductivity would be superior to the less dense fibres and vice versa [7]. The electrical properties of materials were once solely assigned within the scope of electronic engineering and science applications. Such properties have now been incorporated into smart textiles or e-textiles, and they are found crucial in certain types of fibres, yarns called electrically conductive yarns. There are several processes for producing electrically conductive yarns. In staple yarns, it is possible to spin short strands of regular yarns with metal yarns. However, the most important method to produce conductive yarn is coating a base yarn with metalized material. Such as coating silver on base polymer, including polyester or polyamide. They can also be produced from nanoparticles such as carbon nanotubes. The temperature (ageing process, physical properties of the structures changes due to heat/temperature factor and it's as important to benefit the textiles), and humidity are the key parameters in the use of materials since they change their electrical properties [8]. The high value-added textiles industry is facing huge problems for e-textiles washing especially. Water and detergent solution effects on silver-coated yarns. Conductive yarn surface damages more during washing with water as compared to the detergent solution [9]. The effects of yarn surface properties for conductive lines on electrical properties have excellent stability. Small pore size yarns have better electrical performance as compared to large pores [10]. Polyethene/multi-walled carbon nanotube coated polyester yarns are made into conductive woven/knitted fabrics. It was observed that these conductive yarns have the lowest electrical resistivity and stabilizing structure [11]. In recent years, the synthesis of lightweight, and flexible materials for electronic textile applications has been increased extensively. Materials like conductive copper wire E-yarn have been found similar application properties and failed after 25 cycles of washing. E-yarn containing Vectran which has high strength fail after more than 15 cycles of washing and tumble-drying. Silver coated were found the best among all conductive yarns due to their electrical properties and flexibility [12]. Features of the electrical charging and dissipation of charges in fabrics containing conductive yarns after washing. Electrical resistance and surface resistivity are the parameters whose values are sensitive to the number of conductive yarns in the fabrics. EMI shielding, lightweight batteries, and molecular electronic devices are made of conductive fabrics [13]. This work is carried out to investigate the effect of temperature and washing on electrical properties of conductive yarns and woven structures for many wearable electronics applications like textile-based sensors, garments, baby suits, military suits, smart socks, etc.

MATERIALS

Conductive polyester yarns plasma coated with gold and silver particles provided by SWICOFIL, Switzerland was used as weft yarns to save the yarn conductivity and breakage. The details of these conductive yarns are provided in table 1. All the conductive yarns provided by SWICOFIL were already coated with silver and gold using the plasma coating technique. Coating a filament yarn by the plasma coating method gives much better wear, a perfect level coating, and little to no conductivity fluctuation compared to usual techniques of coating yarn with metal.

8/1 Ne Polyester yarn was used as warp yarn and warping of 1.5 m was completed on a sample warping machine (CCI LUTAN 2.500). Polyester was chosen for warp yarn due to its low water absorption.

Table 1

SPECIFICATIONS OF CONDUCTIVE YARNS USED IN THE WEFT DIRECTION

Sr. no.	Substrate	Count	Resultant/ measured dtex	Metal	Characteristic name (mg/m)	Electrical resistance (Ohm/cm)
S1	PET FDY*	dtex (150) f (48) (Z) (60) (pre-twist)**	174	Ag	2.5	5
S2	PET FDY	dtex 150 f 48 Z200 (60 pre; 140 post-twist)	176	Ag	2.7	3–5
S3	PET high ten.	dtex 440 f 96 S 80 rauh special construction	444	Ag	14	0.26
S4	PET FDY	dtex 150 f 48 S 60	172	Au	2.15	30

Note: *Fully drawn yarn; **count (value) number of filaments f (value) direction of twist (Z/S) (number of twists) (additional remarks).

DESIGN OF EXPERIMENT

The electrical properties of the sized yarn and the sized fabric were measured after each wash and subjected to ageing after each wash. A total of three washes was done. The weight of the yarn and fabric was measured before and after wash. The areal contraction was also measured. Four samples S1, S2, S3, S4 were weaved having the same weave design, material, and ends/inch and picks/inch. To produce the fabric samples, a semi-automatic loom as shown in figure 2, was used and four samples were prepared by the 4/1 satin weave method of 5 inches width and the length of each sample is 4 inches as shown in figure 2, *b*. 50 dents per inch reed were used.

a

b

Fig. 2. Graphical representation of: *a* – semi-automatic weaving loom used for sample preparation; *b* – sample top view

METHODOLOGY

Sizing of both yarns and fabrics was done. The major purpose of sizing is to increase the weave ability for fabric production. It also adds to the strength of warp yarn as well as increases the frictional resistance which results in less damage of warp yarn increasing the quality of the product. Later, size materials were not removed due to the possibility of fibre attack, fibre damage, and less variety of application methods. The sizing machine and warping machine details are shown in table 2. The sizing chemicals are shown in table 3.

Table 2

SIZING, AND WARPING MACHINE SPECIFICATIONS			
Sr. no.	**Name**	**Model**	**Manufacturer**
1	Sizing machine	SS-5600	TAIWAN
2	Warping machine	LUTAN-2.500	TAIWAN

Table 3

CHEMICAL'S SPECIFICATIONS			
Sr. no.	**Name**	**Function**	**Manufacturer**
1	PVA	To provide strength	Kuraray Co. Ltd Japan
2	Starch	Binding agent	Rafhan Pvt. Ind. Pakistan
3	Softener	To make yarn pliable	BASF Co. Ltd Pakistan

To size the given yarn samples, first, the size recipe was prepared by adding 50 grams of polyvinyl alcohol in 200 litres of water along with 2% starch. Then the recipe was fed to the single-end sizing machine. A 1000 meters length of sized yarn was produced. Washing of yarn was done manually at room temperature. The warm water of 40° was taken in a 100 ml beaker. 1 gram of detergent was added to the beaker. A yarn sample of 30 cm length was cut and added to the beaker. The water was stirred for 20 minutes. After that yarn could dry.

The fabric was washed by using NaOH detergent in the process for 40 minutes at 40°C having a speed of 25 cycles/min was done according to the standard: ISO 6330:2012 by wascator FOM71 CLS. Ageing (temperature) of samples was done after each wash. 1st ageing was done by placing the samples at room temperature for 24 hours. The second ageing is done after the second wash by the same procedure. But third ageing was done in the oven for 2 hours at 94°C temperatures.

To check the conductivity of the fabric samples before washing, we used a multimeter. The electrical resistance of single conductive yarn was measured using Keithley Source Measuring Unit 2450. This test procedure for measuring the resistance of yarns and woven fabrics was adapted according to standard AATCC 84 and AATCC 76, respectively. Resistance was noted down from 5 different places of the yarn and a mean value was calculated.

RESULTS AND DISCUSSION

The effect of temperature and hand washing on the electrical resistance of conductive yarn was measured as shown in table 4. The electrical resistance was measured after consecutive three washes. Ageing was done after each wash according to the procedure specified earlier. The results suggest that the electrical resistance of the yarn increases slightly after each wash. However, ageing does not affect the electrical resistance of conductive yarn. After washing

Table 4

EFFECT OF TEMPERATURE AND WASHING ON ELECTRICAL PROPERTIES OF CONDUCTIVE YARNS										
Sr. no.	**Sample**	**Electrical resistance specified by the manufacturer (Ohm/cm)**	**Actual measured electrical resistance (Ohm/cm)**	**Ageing after 1st wash (Ohm/cm)**	**Electrical resistance after 1st wash (Ohm/cm)**	**Ageing after 2nd wash (Ohm/cm)**	**Electrical resistance after 2nd wash (Ohm/cm)**	**Ageing after 3rd wash (Ohm/cm)**	**Electrical resistance after 3rd wash (Ohm/cm)**	
S1	Dtex 150 f48 z60 pre twist	5	5.5 ± 3.8	Unchanged	5.59 ± 4.9	Unchanged	6.01 ± 4.7	6.017 ± 5.2	6.03 ± 4.2	
S2	Dtex 150 f48 z200 60 pre-140 pro twist	3–5	3–5 ± 2.7	Unchanged	3.3 ± 2.4	Unchanged	3.39 ± 2.1	3.41 ± 6.0	3.41 ± 2.9	
S3	Dtex 440 f96 s80 rauh special construction	0.26	0.61 ± 2.5	Unchanged	0.65–0.75 ± 3.0	Unchanged	0.88 ± 4.1	0.91 ± 5.4	0.90 ± 4.4	
S4	Dtex 150 f48 s60	30	30–40 ± 11.5	Unchanged	40.5 ± 12.34	Unchanged	44.1 ± 13.0	45.2 ± 11.4	44.3 ± 11.7	

samples for the first time, the conductivity was measured. Conductivity check was followed by the second time wash of the samples to study the effects of washing.

All the sample's weight was measured on a digital weighing machine before and after wash as shown in table 5. The results suggest that the weight of the sample decreases by up to 11% after washing for silver-coated and 7.53% for gold-coated yarn.

The effect of temperature and washing on the electrical resistance of conductive fabric was measured as shown in table 6. After making woven conductive samples, the measured resistivity was insignificant. With a very high conductance, the minimum value of resistance remained 0.007 Ohm/cm^2 and the highest value was 0.02 Ohm/cm^2.

After the first wash, some of the conductive material was removed. But still, the fabric samples were conductive.

Table 5

CHEMICAL'S SPECIFICATIONS				
Sr. no.	**Sample**	**Mass before washing (g)**	**Mass after washing (g)**	**Percentage decrease (%)**
S1	Dtex 150 f48 z60 pre twist	0.0185	0.00177	4.51
S2	Dtex 150 f48 z200 60 pre-140 pro twist	0.0240	0.0231	3.89
S3	Dtex 440 f96 s80 rauh special construction	0.0410	0.0369	11.11
S4	Dtex 150 f48 s60	0.0214	0.0199	7.53

Table 6

EFFECT OF TEMPERATURE AND WASHING ON THE ELECTRICAL RESISTANCE OF WOVEN FABRICS								
Sr. no.	**Sample**	**Before wash resistivity (Ohm/cm^2)**	**After 1st wash resistivity (Ohm/cm^2)**	**Ageing after 1st wash (Ohm/cm^2)**	**After 2nd wash resistivity (Ohm/ cm^2)**	**Ageing after 2nd wash (Ohm/cm^2)**	**After 3rd wash resistivity (Ohm/cm^2)**	**Ageing after 3rd wash (Ohm/cm^2)**
S1	Dtex 150 f48 z60 pre twist	0.008	0.009	Unchanged	0.012	Unchanged	0.19	0.2
S2	Dtex 150 f48 z200 60 pre-140 pro twist	0.007	0.017	Unchanged	0.07	Unchanged	0.01	0.015
S3	Dtex 440 f96 s80 rauh special construction	0.0084	0.011	Unchanged	0.10	Unchanged	0.17	0.18
S4	Dtex 150 f48 s60	0.02	0.036	Unchanged	0.14	Unchanged	1.1	1.17

Table 7

MASS PER UNIT AREA AND AREAL CONTRACTION BEFORE AND AFTER WASHES OF WOVEN FABRICS							
Sr. no.	**Sample**	**Mass/area before washing (g/cm^2)**	**Mass/area after washing (g/cm^2)**	**Percentage decrease (%)**	**Mass/area before washing (g/cm^2)**	**Mass/area after washing (g/cm^2)**	**Contraction percentage (%)**
S1	Dtex 150 f48 z60 pre twist	4.08	3.75	8.2	44.8	43.3	3.46
S2	Dtex 150 f48 z200 60 pre-140 pro twist	3.77	3.41	10.3	51.84	48.5	6.88
S3	Dtex 440 f96 s80 rauh special construction	3.67	3.25	7.69	56.6	52.7	7.09
S4	Dtex 150 f48 s60	3.047	3.47	3.7	49	47.7	2.72

As the minimum value of resistance remained 0.009 Ohm/cm^2 of sample S1 and the highest value was 0.036 Ohm/cm^2 of sample S4. The ageing after 1st wash did not affect the electrical resistance.

After the second wash, the value of resistance was increased, as it got washed. The minimum value was 0.012 Ohm/cm^2 of sample S1 and the maximum value was 0.14 Ohm/cm^2 of sample S4.

But the third wash decreased the sample's properties because a lot of conductive material was removed, and the fabric was considered still conductive. The minimum value of resistivity measured was 0.01 Ohm/cm^2 of sample S2 and the maximum 1.1 Ohm/cm^2 was of sample S4. The 3rd ageing was done by keeping the samples in the oven for 2 hours at an elevated temperature of 94°C. The results show that resistivity slightly increases by increasing the temperature of samples.

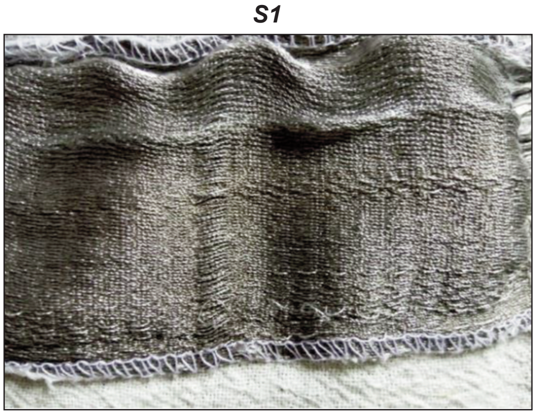
The fabric mass per unit area before wash and after three washes was measured and shown in table 7. The results suggest that a mass reduction of 10.3% maximum is attained after three washes. Whereas the maximum fabric area contraction of 7.09% is achieved. The woven samples after 3rd wash are shown in figure 3.

CONCLUSION

The effect of washing and temperature on the electrical properties of conductive yarns and fabric was measured. The fabric was constructed using

S1

S2



S3

S4

Fig. 3. Woven samples S1, S2, S3, and S4 after 3rd wash

polyester yarn as warp yarn and conductive yarn as weft yarn. Satin 4/1 weave was used for the construction of the fabric. The effect of washing on sized conductive yarn suggests that electrical resistance slightly increases, and the mass of the conductive yarn is reduced up to 11% showing conductive material is removed. The silver yarn is more conductive than gold-coated yarn. Out of four conductive fabric samples, the silver-coated sample S2 has excellent conductive properties. The rest samples also show good conductive properties but as far as conductivity is concerned, the fabric made from gold-coated yarns shows poor conductivity than fabric made from silver-coated yarns. The resistivity slightly increases after each wash. But the fabrics failed to retain and maintain the conductivity after three washes and are highly non-conductive suggesting the fabrics are wasted. The ageing after each wash does not affect electrical properties. However, ageing at an elevated temperature after the 3rd wash slightly increases the resistivity suggesting increasing the temperature of fabric decreases the conductivity of fabric. The fabric contracts after each wash and the mass per unit area are reduced after 3rd wash showing that conductive material is removed.

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