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Electromechanical properties of polyamide/lycra fabric treated with PEDOT:PSS

M G Tadesse[1, 2, 3], D A Mengistie[4], C Loghin[2], Y Chen[3], L Wang[3], D Catalin[5], C Müller[4], and V Nierstrasz[1]

[1]Textile Materials Technology, Department of Textile Technology, The Swedish School of Textiles, Faculty of Textiles, Engineering and Business, University of Borås, 501 90 Borås, Sweden

[2]Faculties of Textiles, Leather and Industrial Management, Gheorghe Asachi Technical University of Iasi, 53, D.Mangeron Blv. Iasi-700050, Romania

[3]College of Textile and Clothing Engineering, Soochow University,178 Gan Jiang Dong Road, 215021 Suzhou, China

[4]Departments of Chemistry and Chemical Engineering, Chalmers University of Technology, 412 96 Goteborg, Sweden

[5]Faculty of Machine Manufacturing and Industrial Management, Gheorghe Asachi Technical University of Iasi 53, D.Mangeron Blv., Iasi-700050, Romania

E-mail: melkie.tadesse@hb.se , tadesse.melkie@tuiasi.ro

Abstract. One of the challenges in smart textiles is to develop suitable multifunctional materials that can address simultaneously several characteristics such as durability, stretchability, lightweight, and conductivity. Conductive polymers which showed success in different technological fields like polymer solar cells and light emitting diodes are promising in many smart textile applications. In this work, we treated a common polyamide/lycra knitted fabric with PEDOT:PSS for stretchable e-textiles. PEDOT:PSS, with DMSO as a conductivity enhancer and different ratios of water-based polyurethane dispersions as a binder, was applied to the fabric with simple immersion and coating applications. The effect of different application methods and binder ratio on the surface resistance of the fabric was monitored with four point probe electrical surface resistance measurement systems. Samples prepared by immersion technique are more uniform and have higher conductivity than those prepared by a coating technique. SEM images showed that PEDOT:PSS is incorporated into the structure in the immersion method while in the coating it is majorly present on the surface of the fabric. The tensile measurement showed that the acidic PEDOT:PSS and polyurethane dispersion coating has no adverse effect on the tensile strength of the fabric. The coated samples can be stretched up to 700% while still reasonably conductive. The resistance increases only by a small amount when samples were stretched cyclically by stretching 100%. Generally, samples prepared by the immersion method maintained better conductivity while stretching than those by a coating method. The washing fastness of the samples was also assessed.

Keywords: Polyamide/lycra, PEDOT:PSS, stretchable conductive fabric, immersion, coating.

1. Introduction
Recently most research focus on producing lightweight, flexible, and stretchable conductive textile materials to fill different interests of human beings. Electrical and mechanical properties have become increasingly important and widely used in characterizing smart materials, such as flexible electronic displays [1], and conductive stretchable materials [2]. There are a lot of intrinsically conductive polymers that gained recent attention. Among these polymers, poly (3, 4-ethylenedioxythiophene): poly (styrene-sulfonate) (PEDOT:PSS) is interesting materials due to its electromechanical properties, such as in chemical sensors and biosensors [3]. Attempts have been made to produce stretchable electronic materials such as stretchable interconnects using thin gold films on elastomeric membranes [4]; conductive PEDOT:PSS on stretchable poly-(dimethylsiloxane) (PDMS) substrate. But, the conductivity decreases rapidly as strain applies up to it. Silver-coated conductive yarns made into an e-textile using knitting operation and the resistance has been tested against stretching [5]. Similarly, a lot of efforts have been made improve strain sensitivity and flexibility of electronic materials. Among these, integrating textile materials with an electronic application such as coating nylon-lycra fabric with polypyrrole (PPy) for stretchable supercapacitor, However, PPy has limited practical application due to lack of mechanical properties and poor processability [6]. The most important feature of conductive polymer-coated fabrics is the stretching induced change in surface resistance, offering the coated and immersed fabric stable applications as e-textiles. As a result, being flexible, stretchable, and even lightweight properties becomes possible. Therefore, in order to overcome these challenges, the idea of producing electrically conducting textiles has become important for various applications such as serving as electrodes and active materials for various energy and electronics devices.
In this study, we extend the application of PEDOT:PSS polymer to polyamide/lycra knitted fabric using immersion and coating techniques, and studied the electrical and mechanical properties and its sensitivity to strain and cyclic strain, and washing stability.

2. Experimental
2.1 Materials
Polyamide/lycra knitted fabric with 78/44 Dtex; 0.74 mm thickness was used for immersion and coating using PEDOT:PSS with a concentration of 1.3% by weight from Heraeus, GmbH, Germany. Dimethyl sulfoxide (99.8%), from Sigma-Aldrich, water-based polyurethane dispersions (U2101, U3251, and U4101) (40-60 wt%) from Alberdingk Boley, were used as conductivity enhancer and binder, respectively. In order to improve the rheology, in the case of coating application, we used Gel L75N (48 wt%); hydrophobically modified ethoxylated urethane from Borchers GmbH, Germany.

2.2 Methods
Coating and immersing polyamide/lycra fabrics in an aqueous dispersion of PEDOT:PSS, various water-based polyurethane dispersion binders, and rheology modifier (for coating only) followed by drying at 90ºC for 30 min and curing at 130ºC for 5 min, conductive PEDOT:PSS-coated and immersed fabrics were prepared. The electrical surface resistance was measured via an in-house designed four point probe method connected to a multimeter (Agilent 3401A) using Van der Pauw method. Tensile testing of samples was carried out with an Instron tensile tester (model 5565A) at a cross-head speed of 10 mm min $^{-1}$. The measurements were taken both in the warp and weft directions for three times, and the averages were reported. Domestic laundry washes and drying procedures of Type 3A reference with a standard for washing textile testing (ISO 6330:2012), were performed to observe the durability of the conductivity of immersed and coated samples against washing with 100% polyester ballast against. Scanning Electron Microscopy images were taken with a Leo Ultra 55 SEM equipped with a field emission gun (LEO Electron Microscopy Group, Germany) and a secondary electron detector. The acceleration voltage was 3 kV. Samples were cut by a razor blade. Untreated sample was sputtered with gold.

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3. Results and discussion

One of the most important parameters in e-textiles is conductivity, which affects the performance of e-textiles. It was measured that the surface resistances of PEDOT:PSS-coated and immersed fabrics were about 2-20 and 9-65 kΩ/square using immersion and coating methods, respectively. It can be seen that the two kinds of producing conductive fabrics exhibited different orders of surface resistance values with the same amount of PEDOT:PSS concentration. In both cases, lower electrical resistance was observed when the fabric was treated using immersion method. This could be attributed to in immersion methods the PEDOT:PSS was sufficiently incorporated onto the surface of the fabric.

It is obvious that as the concentration of PU dispersion increases, the surface resistance values increases. The result clearly showed that immersion method gave better electrical conductivity results than the coating method. This means in immersion the PEDOT:PSS is sufficiently absorbed into the interior of the fabric as evidenced by the SEM image in **Figure 1**.

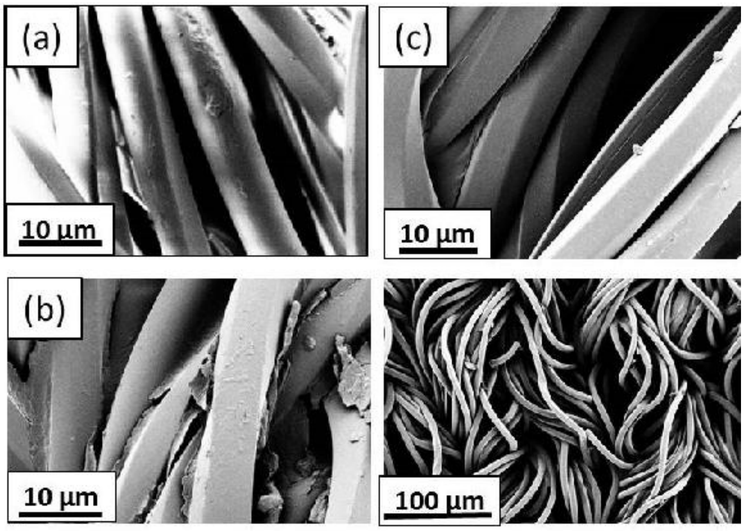

Figure 1. SEM images of (a) uncoated (b) coated, and (c, d) immersed samples.

Washing fastness is an important parameter for any textile finishing. The washing fastness with various concentrations of PU dispersions in immersion methods was also checked, and the result confirmed that the samples were still reasonably conductive after 10 washing cycles.

The surface morphologies of the conductive fabrics were investigated using scanning electron micrograph (SEM), and SEM images showed that PEDOT:PSS is incorporated into the structure in the immersion method while in the coating it is majorly present on the surface of the fabric. These aggregates of PEDOT:PSS and PU dispersion into the fabric surface make the conductive surface resistive to vigorous washing actions which indicate their strong adherence to the PEDOT:PSS coated layer. For this reason, low surface resistance was observed in immersion samples. The tensile measurement showed that the acidic PEDOT:PSS, polyurethane dispersion coating has no adverse effect on the tensile strength of the fabric as shown in **figure 2.**

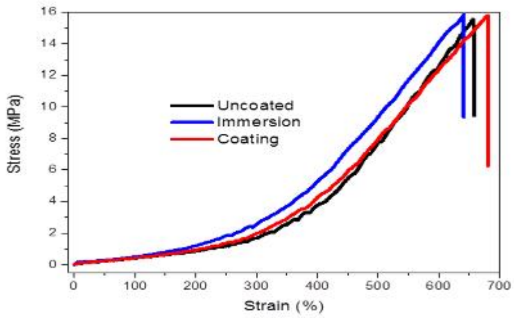

Figure 2. Stress-strain graph of samples.

The surface resistance was almost back to its original value after one minute relaxation time. The electrical surface resistance increased during elongation process and decreased during relaxation process with 100% extension. This could be attributed to polymer film breaks apart during elongation; even though there is better contact within fabric when stretching. The coated samples can be stretched up to 700% while still reasonably conductive. The surface resistance showed increased value after 400% stretching. The resistance increases only by a small amount when samples were stretched cyclically by stretching 100%. Generally, samples prepared by the immersion method maintained better conductivity while stretching than those by a coating method.

4. Conclusion

The stress-strain measurement showed that the acidic PEDOT:PSS coating has no adverse effect on the tensile strength of the fabric. The coated samples can be stretched up to 700 % while still reasonably conductive. The resistance increases only by a small amount when samples were stretched cyclically by stretching 100 %. The SEM image showed that immersion brought better result than coating such that in immersion the PEDOT:PSS was attached to the surface of the fabric evenly. Samples prepared by the immersion method maintained better conductivity while stretching than those by a coating method and showed better performance against washing.

Acknowledgments

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