Market readiness of smart textile structures – reliability and washability

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Abstract. Even if smart textiles gained a certain level of maturity, they are not yet ready for the market at large scale. The main issues explaining this are related to problems of reliability and difficulties to launder smart textile structures. Smart textiles are also facing problems for launching in market due to lack of standardizations. This paper is focused on washability standards of smart textiles. The objective is to correlate available textile mechanical tests with the washing of smart textiles and to observe the change in their performances. First, different washing functions and washing factors acting in laundering machines are analysed and discussed. Then Martindale abrasion tests and pilling box tests were performed in order to detect damages similar to those provoked by washing process. Two different types of silver coated conductive threads sewn on cotton plain woven fabric are used. Changes in threads resistance during these tests are analysed and correlated with modifications of electrical conductivity after washing of the similar samples. Therefore, the mechanical stresses underwent by conductive threads during washing cycle have been identified and reproduced by standardized testing equipment. More generally, this paper emphasizes all the problems, encompassing efforts that industry and research labs have to realize to make smart textile structures more robust and able to be cleaned or washed similarly to everyday textile products such as underwear, clothing, home textiles and even technical textiles. It gives indications on how the issues related to reliability and washability of smart textile structures have to be addressed in order to make them reliable and robust enough to be put on the market.

1. Introduction

Smart textile, also called e-textile, involves wearable electronic industry that is penetrating in our daily life now days. This new developing sector has captured numerous fields of applications including different trends in leisure and sports, some lifesavings in health care, security and military. In initial stages of this industry, main focus was on to use e-textile in healthcare applications. Although now, smart textile is being used widely in other fields like wireless communication, smart sporting, smart watches, monitoring etc. [1] Printed electronics and energy harvesting technologies are evolving to meet the demands of new, wearable formats. Next-generation wearables and smart technical textiles will rely on active fabrics conductor, insulator and semiconductor fibers. These products will integrate electronic functions with everyday comfortability of clothing and thus enhance the user experience [2]. Smart textiles can be defined as textiles that are able to sense and respond to changes in their environment. Conductive polymers and metals may be integrated in to e-textile structure for suppling
conductivity. These conductive yarns should maintain the minimum requirement for conductivity and also physical characteristics [3]. In broader view, smart textile can have three types of components.

Smart textile can have electronic modules equipped with a micro controller, memory and input output interfaces and it is dedicated to data processing and decision purposes. Smart textile can contain sensors, actuators and electrodes. These are normally used to detect external stimuli. Smart textile can contain connecting conductive yarn with different types of assembling techniques, used for connections among antennas, sensors and modules.

Even if smart textiles gained a certain level of maturity, they are not yet ready for the market at large scale. The main issues explaining this are related to problems of reliability and difficulties to launder smart textile structures. Washability of smart textile is one of the major hurdles to launch the product in market as user friendly and reduces the reliability of the product. These connecting yarns are more difficult to protect especially at connection points between yarn and sensors, actuators etc. Actually, interface between hard and soft point is the weakest point in smart textile structure increasing risks to be damaged within washing process. This is a big barrier to their readiness to market.

Washability of smart textile has gained attention now days and a lot of work is has been performed to make washable ready to market smart textile products. Washing itself is complex process as so many factors are involved in it. Numerous chemical and physical forces are acting during this process. Washing process is also sensitive to clothing type, quality of water, type of detergent and washing procedure adopted. Mechanical actions can be explained in term of abrasion among surfaces of textile structures, and with the wall of washing drum, hydrodynamic flow of solution and flexing action etc. [4].

Before analysing the effect of washing cycle on conductive yarns, it is important to analyse influences and stresses underwent by smart textiles during it. A washing cycle may be decomposed in four different damaging actions with possible interactions: mechanical stress (bending, torsion, friction, etc.), thermal stress (temperature), water stress and chemical influence (detergent) [5]. The mechanical stress is probably the most damaging factor on smart textile structures, particularly on conductive yarns dedicated to connect electronic modules with sensors & actuators and the interconnection between the conductive yarn and the electronic component in e-textile.

For washing of smart textile, there are two possibilities. One is laboratory standardized washing procedure and the other is washing in household washing machines. In order to be successful in smart textiles, products should be able to withstand washing in normal washing machines as ultimately they will be laundered. For these reasons, the focus is on commercially available washing machines. They have different washing cycles with difference in time, washing speed and drying capabilities.

2. Procedure & Experiment
To make smart textile reliable and washable, it is compulsory to understand exactly what is actually happening during laundering with lot of constraints that are playing role in the sample. These constraints can be explained as mechanical forces, chemical actions with detergent, water influence, effect of temperature and washing time. These washing factors are shortlisted in Figure 1. For reliability and washability, smart textile should withstand in all these circumstances. Smart textile can be performed in these pre-defined situations to predict their washability. However, all these constraints are interlinked to each other and interdependent. Their effect can be changed when performed independent to each other. One example is effect of water on smart textile that may be different in idle state as compared with effect during some mechanical forcing, such as abrasion; bending or frictions acting on it mechanical forcing, such as abrasion; bending or frictions are acting on it.

Among all these washing factors, the mechanical stress during washing cycles is factor that is difficult to control. Standardized available mechanical tests textiles have been performed and then these test results were correlated with washability of smart textiles. During washing, samples are rubbed with other clothes and also with walls in washing drum of machine. These actions are supposed to have major effect on smart textiles durability. Martindale abrasion test can be considered
as substitute to verify the effect on conductive yarns as the weak point of smart textiles without washing the samples.

Two conductive yarns from different companies were used. These yarns are marked as yarn A and B. Both yarns were continuous filament polyamide silver coated yarns. They were two ply yarns consist of 117 fibres each having 20 μm diameters. These conductive yarns, of known length, were stitched on plain cotton fabric. Silver paste was pasted on stitched ends points of yarn to avoid wear off during mechanical abrasion. Martindale abrasion tests were performed on Martindale Abrasion Tester by James H. Heals & Co Ltd. Load on samples during testing was 9 KPa and woven felt was used. Unidirectional movement of Martindale top motion plate was selected. Linear resistance was measured after each 500 abrasion cycles up to 3000 cycles.

![Washing Procedure](image)

**Figure 1(a)** Factors involved in washing process, **(b)** Mechanical factors involved in washing process.

For washing of samples “Silk” washing process was selected on local consumer used washing machine. Reason behind this selection was gentle washing and no interim tumbling during rinsing. Washing speed was 15 revolutions per minute (rpm), while tumbling speed was 400 rpm. Samples were dried after each washing at controlled room conditions (65%±5% R.H and 25°C± 2°C). Linear resistance was measured by Agilent digital multi meter using standard probes.

3. Results & Discussion
Abrasion test was performed in the group of 500 cycles for total 3000 abrasion cycles and linear resistance was measured after every 500 cycles. Average linear resistance against abrasion cycles is shown in Figure 2 for both yarns A and B. Resistance increases with increase in number of abrasion cycles. Thin black line shows fitted linear trend and thick blue line shows actual values. Fitted linear equation with R square values are in the graph. R square value for yarn A is better as compared to yarn
B. A sharp increase of electric resistance is observed at beginning of wash process. This initial damage of conductive layer on yarns maybe due to the damage of superficial silver, which are not strongly adhered onto the surface of thread.

**Abrasion Resistance**

![Graph showing abrasion resistance for Yarn A and Yarn B](image)

*Figure 2. Linear Resistance after abrasion cycles for Yarn A & Yarn B*

**Washing**

![Graph showing washing resistance for Yarn A and Yarn B](image)

*Figure 3. Linear resistance after washing for Yarn A & Yarn B*
Also, at initial stage, the temperature of surface increases from low to high with the abrasion cycle. That’s why at initial stage abrupt change is observed and afterward straight line was noted. For yarn A initial value of conductive thread was $1.10 \, \Omega/cm$ and increased to $3.17 \, \Omega/cm$ after 3000 abrasion cycles. For yarn B initial value was $1.87 \, \Omega/cm$ and increased to $3.21 \, \Omega/cm$ after 3000 abrasion cycles. In comparison yarn A has less initial value as compared to yarn B, but after 3000 cycles both yarns have almost same values. This means change in resistance is more important in yarn A as compared to yarn B.

Figure 3 shows the resistance per centimetre against number of washing cycles. This trend is also linear as in abrasion cycle experiment. Thin black line shows linear trend and thick blue line is actual values. Fitted linear equation and R square values for both yarn A and B are given in graph. R square value for both yarn A and yarn B are almost same and near to 1. This shows better linear trend for both yarns A and B. For yarn A resistance increased to $2.88 \, \Omega/cm$ after ten washing cycles. For yarn B it was $3.6 \, \Omega/cm$ after ten washing cycles. After washing, change in resistance in yarn B was more as compared by yarn A. Figure 4 shows the co relation between abrasion resistance effect and washing effect on smart textile proto types. For both yarns it can be predicted that 1500 abrasion cycles is equivalence to about 7 washing cycles (keeping in mind the washing type selected for this experiment). These experiments are initial outcomes for co-relation of mechanical tests with washing of smart textiles. Further experiments in future can give the final statement about the relation.

**Washing vs Abrasion Cycles**

- Washing Yarn A
- Washing Yarn B
- Abrasion resistance Yarn A
- Abrasion resistance Yarn B

**Figure 4.** Co-relation between washing and abrasion resistance

Figure 5 shows the optical microscopic picture of conductive yarn at initial stage, after washing and after abrasion resistance. These pictures clearly point out the whitish damaged spots after washing and abrasion tests. These both tests involve mechanical movements and wear and tear that cause damage of surface. These spots are created due to damage of silver layer that is responsible for conductivity of yarn. These damaged parts caused the increase in resistance and decrease in conductivity of conductive yarn.
Figure 5. Microscopic picture of yarn (a) Initial stage, (b) After washing, (c) After abrasion test

4. Conclusion
The importance of standardization and establishment of tests able to fit to the laundering of smart textiles have been studied in this work. First approach to simulation of mechanical stresses underwent by conductive threads embedded to textile fabric, necessary to connect and supply sensors, actuators and electronic modules contained in smart textiles has been set up. The final objective of our research work is to establish standards and tests supposed to help companies involved in e-textiles development to meet market demands and realize reliable and washable products.

5. References
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