

STUDY ON THE DURABILITY OF CONDUCTIVE EMBROIDED YARNS FOR APPLICATION IN INTERACTIVE TEXTILES

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ABSTRACT

Interactive textiles based on electrically conductive yarns are being extensively researched due to its ability to functionalize fibrous structures, leading to a high interactivity with the user. The aim of this study was to evaluate the durability of interactive embroidered 100 % cotton fabrics, incorporating flexible conductive yarns composed of 77 % polyamide (PA) and 23 % silver (Ag) (30 tex) when subjected to wear factors such as washing, abrasion, creasing and stretching cyclic tests. The conductive yarns were incorporated on the fabric at two different widths of 2 to 10 mm, keeping a constant length of 10 cm. In order to study the durability of these materials, the fabrics were subjected to different washing cycles, according to the standard NP EN ISO 6330:2002, and to various abrasion cycles, according to the standard NPEN ISO 12947:1999 showing an increased electrical resistance when testing time is increased. The increase on the electric resistance was more significant in the 2 mm width sample rather than the 10 mm sample. The recovery from creasing, measured according to standard NP EN 22313:1993, was further assessed and no significant changes were observed. It could be concluded that the durability of conductive embroidered textile substrates in terms of washing and abrasion is highly dependent on the width of the conductive yarns embroidered area to perform the function. Larger conductive embroidered areas were found to be significantly more stable to wear factors.

Keywords: Interactive textiles, conductive embroidery, conductive yarns, durability.

INTRODUCTION

For years, the aesthetic aspect of textiles was the most important characteristic for their commercialization. However, the textile sector is now facing a new challenge with the generation of smart and interactive textiles (1). These are fibrous structures capable of sensing, actuating, generating/storing power and/or communicating. In fact, research and development towards wearable textile-based personal systems allowing for health monitoring, protection and safety, and healthy lifestyle has gained strong interest during the last 10 years (2). It is well known that by including lead wires in a fabric it is possible to obtain different characteristics in terms of interactivity, sensors, lights, audible alerts, among others, in order to enhance the cognitive development by a user (3). The conductors may be defined as pure metal based



wires or compounds of metals and non-conductive yarns, which helps to improve the mechanical properties thereof. The integration of these materials into a fibrous substrate allows for imparting various functionalities conductive reliably applications, since these materials can be used on fabric, knitting, sewing and embroidery (4). Herein, we aimed at developing novel fibrous conductive structures to implement into a home textile product (e.g. blanket embroidered with cartoons) in order to include novel features such as improved interactivity with the children.

MATERIALS AND EXPERIMENTAL METHODS

Materials:

In this study the substrates were embroidered with two types of conductive structures with 10 cm in length, on of it with 2 mm width and the other with 10 mm in width. The conductive yarn was composed by polyamide (PA) multifilament yarn coated with silver (Ag) particles. Table 1 shows the composition the conductive yarn.

Table 1.Characterization of Polyamide/ Silver (PA/Ag) conductive yarn used in this study.

Parameter	Composition (%)	Linear density (tex)	Twist (number of turns/m)	Type of Twist	Friction Coefficient (μ)
Conductive yarn	77 Polyamide/ 23Silver	30 ± 1%	583 ± 6%	S	(0,25 - 0,28)

Methods:

Resistance to domestic washing: In order to evaluate the conductive properties after domestic washing, 20 washings were performed according to the standard NP EN 26330, using the 7A washing procedure. Briefly, it was applied a temperature of 40 °C and a washing load of 2 kg. The results were further analysed by reading the electrical resistance across the terminals of each substrate, after each washing and drying cycles. This test allows to verify if the structures maintain their conductive properties after repeated washings and determining the ability/functionality of the conductive textile after home laundering.

Abrasion Resistance test: The test to evaluate the resistance of materials to abrasion was performed in agreement with the standard ISO 12947 - 2: "Determination of the abrasion resistance of fabrics by the Martindale method - Part 2: Determination of specimen breakdown". A 794 grams load was applied on the fabrics, which represents a pressure of 12 kPa. The evaluation of the embroidery conductivity was performed through the direct method, by measuring the resistance between the two ends with a digital multimeter. From the moment that the embroidery lost their conductive properties no more measurements were carried out since they no longer had the desired characteristics. Table 2 shows the frequency of stops in function of the number of cycles performed. Figure 2 shows the arrangement of samples in the Martindale machine.



Table 2. Frequency of stops in function of the number of cycles performed.

Number of cycles	Stops (cycles)
≤ 2000	Each 500
> 2000 ≤ 4000	Each 1000
>4000 ≤ 10000	Each 2000
>10000 ≤ 40000	Each 10000
>40000 ≤ 80000	Each 40000



Figure 1. Representation of the 2 mm and 10 mm width at Martindale equipment.

Crease resistance test: To evaluate the resistance to crease a load of 10N was applied for 1h on the samples in order to induce a crease, as depicted in Figure 2. Then the measurement of electric resistance is carried out with a digital multimeter.



Figure 2. Load application on the samples for the crease resistance tests.

Tensile strength test: A stress-strain test was performed to two samples of 2 mm and 10 mm embroidered in 100% cotton fabric. The aim was to analyse the behaviour of the mixture (fabric + embroidery) on the edge (rupture), to further perform a cyclic testing that simulates the stretch that home textiles suffer when are placed in a bed.

Stretching cyclic tests: The electrical resistance was measured under stretching cycles using the Hounsfield equipment. The clamping distance was set at 200 mm. Each sample was measured with 50% of maximum elongation as determined in the stress-strain test. The stretch-recovery speed was a constant 100 mm/s. The resistance of the PA/Ag-containing embroidered samples was then evaluated with a digital multimeter and the data obtained by a software developed within our group using the program MatLab.

RESULTS

By analysing the results of resistance to domestic washing of the embroidered structures comprising the conductive yarns composed of a mixture of PA/Ag it could be seen that the electrical resistance increased exponentially with the number of washing cycles they are subjected to (Figure 3). The structure with a width of 2 mm



had lower performance until since it has shown higher electrical resistance with increasing number of cycles. Since the electrical resistance is the capacity of a body to oppose the passage of an electric current when a potential difference is applied it was concluded that the structure with 10 mm have shown slightly better results in terms of durability of conductivity after 20 washing cycles. This is due to the high redundancy that exists in 10 mm structure owing to the higher amount of conductive wires. Nevertheless, the difference was not as significant as expected when considering the higher quantity of yarns present in the 10 mm structure. It should be noticed that at washing cycle n° 9 the resistance was highly increased in both samples and maintained until washing cycle n° 15. A further increase was observed in both samples until washing cycle n° 20. This indicate that the fabric loses conductivity, mainly after cycle n° 9, probably due to the fact that Ag particles are lost with the washing process.

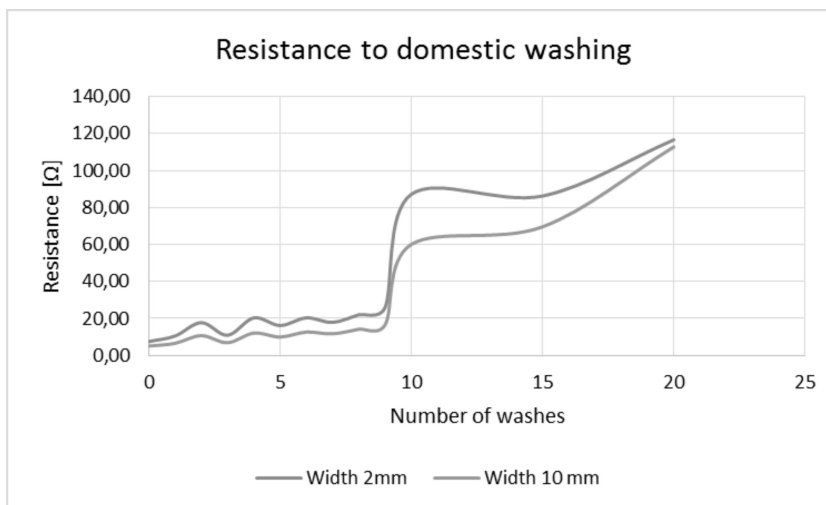


Figure 3. Resistance to domestic washing of PA/Ag embroidery structure with 2 mm and 10 mm width.

Similarly to what was measured in the previous analysis, the electrical resistance of the embroidery was tested after being subjected to a tensile test with a Martindale equipment. The sample was continuously inspected for wear while the sample was pulled taut and loaded onto the lower plates of the Martindale machine. After 40000 cycles the induced abrasion caused a more pronounced increase in the resistance in the 2 mm width structure, reaching the 60 Ω while in the structure with 10 mm width less wear was observed, measured by the lower resistance increase (up to 20 Ω) (Figure 4). Duplicating the number of cycles to 80000 resulted in an increase up to 50 Ω in the case of the 10 mm width structure while a significant increase to 180 Ω was observed to the 2 mm width structure. Similarly to the behaviour of the embroideries tested for domestic washing cycles, the 10 mm width structure have shown the most satisfactory results in terms of resistance to abrasion not losing significant conductivity after 80000 cycles.

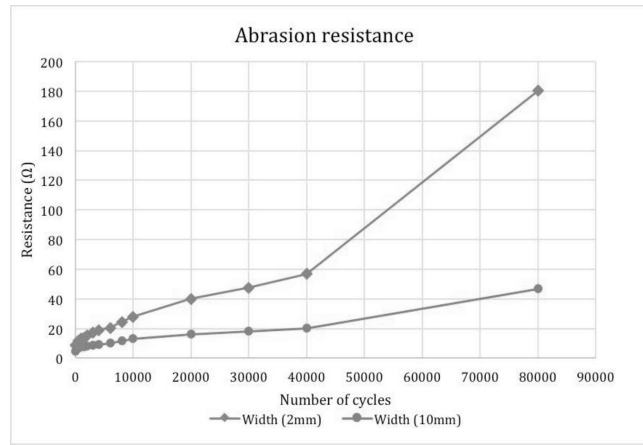


Figure 4. Resistance to abrasion of PA/Ag embroidery with a structure of 2 mm and 10 mm width.

With regard to the crease resistance test it was observed that after applying a load of 10N for a period of 7h no significant variations on the electrical resistance was registered on both samples (Figure 5). It was observed that the PA/Ag yarn in the two embroidery samples indeed possessed satisfactory properties in terms of electrical conductivity, since the electrical resistance of the structures underwent reduced changes.

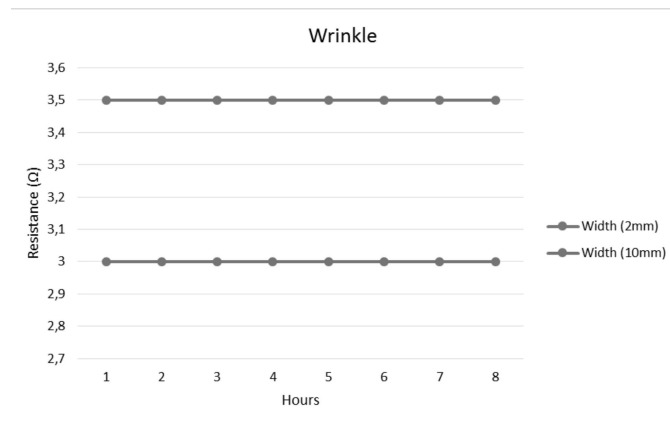


Figure 5 – Resistance measured after applying a 10 N load on the embroidery with 2 mm and 10 mm width for a period of 7h.

Likewise, a stress-strain curve was obtained for the embroidery samples in order to determine which reference stretch values should be used when performing the stretching cyclic tests, a test that simulates the stretch that home textiles suffer when are placed in a bed. As depicted in Figure 6, both embroidery samples possessed similar behaviour in terms of mechanical resistance possessing a breaking force of 500 N.



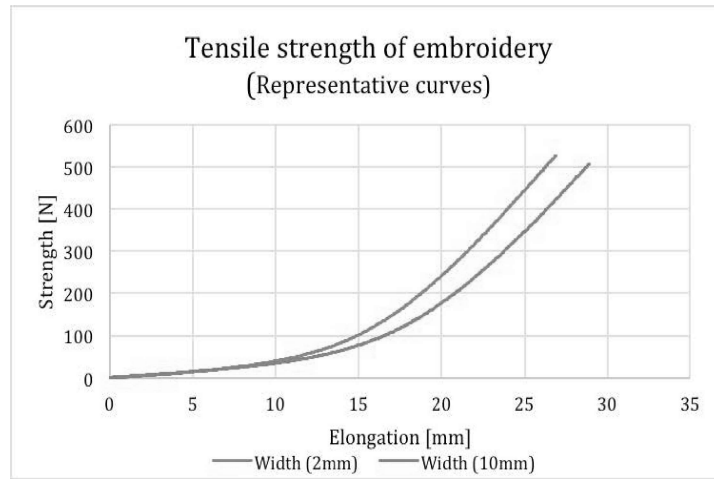


Figure 6 – Stress strain curve for the embroidery with 2 mm and 10 mm width.

Taking into consideration all the tested parameters and that no significant changes were observed between the two samples, we opted to select the embroidery with 2 mm width for the simulation of the stretch applied when handling home textiles, by doing the cyclic testing hysteresis. For the realization of this test we used an elongation of approximately 50 % of the results of the breaking force, which was 20 mm (Figure 6). The test elongates the substrate to a maximum of 20 mm, further withdrawing the strength applied at that time. 10 consecutive cycles of stretching and retreat were performed, with 1 minute break between trials up to a maximum of 10 cycles. The results of the tests are shown in Figure 7. The electrical resistance was increased with the number of cycles applied, increasing from 11.5 Ω in the beginning to a resistance of 14 Ω at the end of the test. These results indicate that no significant loss of conductivity was induced by the test indicating that they can be freely handled at home settings.

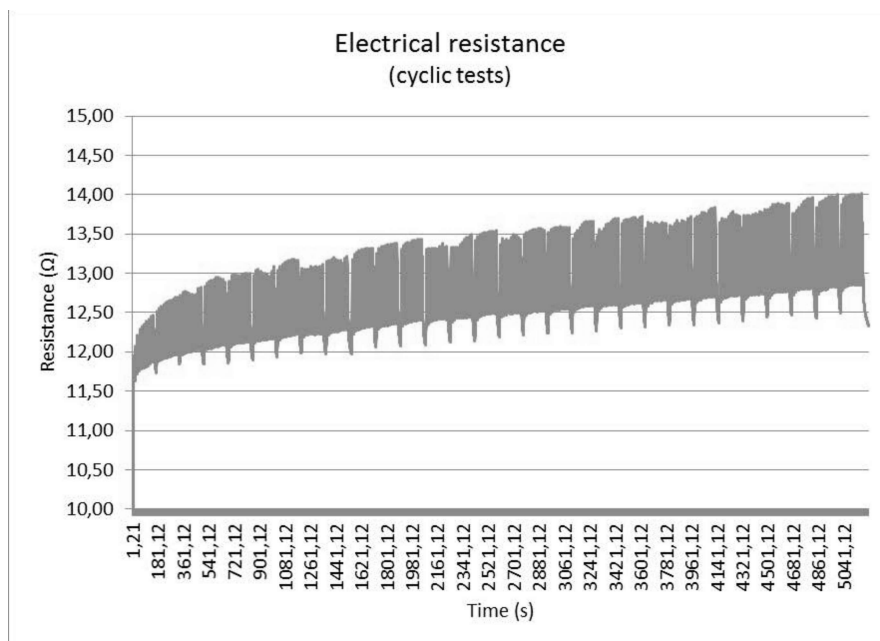


Figure 7 –Electrical resistance upon application of a cyclic tensile strength on embroidery with 2 mm and 10 mm width.

CONCLUSIONS

Embroidery samples containing conductive PA/Ag yarns with two different widths were developed using embroidery technology and further analysed for their electrical durability. Several tests were performed to evaluate the durability of the yarns, which consisted in the evaluation of their electrical resistance when subjected to different wear conditions. It was concluded that after 20 domestic washing cycles and 80000 cycles of abrasion a significant change in resistance was observed mainly for the 2 mm width sample. On the other hand, the 10 mm width sample was less resistant to the electric field passage, which means that it maintained better the conductivity and less damage was induced. Nevertheless, the observed changes were not as significant as expected and despite possessing less conductive yarns, the 2 mm sample still possessed the ability to conduct electricity. With regard to the mechanical properties, no significant changes were observed in both embroidered 2 and 10 mm samples, and in the crease test no influence on the electrical resistance of the conductor yarn was observed. The stretching cyclic test performed with the 2 mm sample indicated that no significant loss of conductivity was induced by the cyclic test demonstrating that they can be freely handled at home settings with loss of functionality. From this study it could be concluded that the embroidery with higher number of conductive yarns provided slightly better results in terms of durability for use in interactive textiles. However, the 2 mm embroidery was also found to possess good functionality in terms of durability. For that reason, for commercialization purposes the 2 mm was defined as appropriate because it presents a good cost-effectiveness relation. It has to be noted that the only wear factor affecting significantly the conductivity of this type of yarns was the domestic washing test. Both analysed structures had shown not to be prepared to withstand several washing steps, so a strategy on how to introduce these conductive materials in home textile fibrous substrates needs to be reconsidered.

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