

THE PROCESSING AND CHARACTERIZATION OF A STRAIN SENSOR ON A TEXTILE

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***Abstract:*** *In this work we present a basic investigation of the integration of a strain sensor onto a woven fabric. The strain sensor is realised by screen-printing technology and consists of a graphite-based piezoresistive layer terminated with a silver conducting layer on the fabric. The number of piezoresistive layers is varied from 1 to 3. After each printing the graphite layer is cured at 120°C for 3 min., whereas the silver conducting layer is cured at 125°C for 10 min. The mechanical properties of the fabric and of the fabric with the integrated sensor were evaluated with a dynamometer. The microstructures of the fabric and the deposited layers were examined using a scanning electron microscope. The layers exhibit a homogeneous structure and surround the microfilaments well. The electrical resistance of the sensor was measured during a tension test. The resistance was found to increase with the increasing load, and the gauge factor of the piezoresistors was calculated.*

Keywords: Smart textile, strain sensor, screen-printing, mechanical properties, electrical properties.

# Introduction

Textiles are an important part of our daily life and we are surrounded by them all the time. However, for the past ten years there has been a trend towards the development of smart textiles [[[1]](#endnote-2)]. Smart textiles are defined as materials and structures that sense and react to environmental conditions or stimuli, such as those from mechanical, thermal, chemical, electrical, magnetic or other sources. They are able to sense and respond to external conditions in a predetermined way. A smart textile can be realised by integrating functional materials into a flexible, lightweight, low-cost textile. Such a textile can then find a wide range of applications, ranging from daily to high-tech usage. Textiles with integrated sensors and microelectronic devices on conventional fabrics have great potential in the areas of medicine, military and industry [[[2]](#endnote-3)]. A textile material is very flexible and can be easily deformed in all directions, so the developed sensor has to be able to follow these mechanical deformations. The extent and the range of the motion can be measured by printing conducting polymers with high resistance and flexibility on flexible materials in order to create a strain sensor [[[3]](#endnote-4)]. Integrating the strain sensor onto the textile opens up a number of new applications, such as measuring pressure, stress and strain [[[4]](#endnote-5)].

A strain sensor is a conventional thick-film resistor configured in such a manner so as to exploit its fundamental piezoresistive properties. When conducting materials are subjected to a deformation by an applied force they exhibit a change in their bulk resistivity. This property is known as the piezoresistivity. The potential use of this effect as a sensing mechanism in the form of a strain gauge was exploited with many materials [[[5]](#endnote-6)]. Fabric-based sensors [[[6]](#endnote-7)] or flexible strain sensors [[[7]](#endnote-8)] to capture motion or biomechanical signals are being developed using many different approaches, such as coating the fibre with a piezoresistive material, by knitting, or weaving the conductive fibres with non-conductive fibres, by wrapping fibres with conducting wires [[[8]](#endnote-9)], or by inkjet printing conductive lines [3]. Screen-printing of a conductive polymer composite onto cotton and nylon fabrics [7] and piezoresistive graphite paste on a polyester monofilament [[[9]](#endnote-10)] are being used to make strain sensors.

The aim of our work was to process and characterise a screen-printed strain sensor on a textile.

# EXPERIMENTAL

The flexible substrate used was 100% polyester fabric from Saati (SAATI SPA, Italy). The weight of the fabric is 48 g/m2 and thickness of the fabric is 60 µm. The working temperature of this fabric is limited to 150°C. Monofilament threads of 31 µm were woven into the fabric using a 2/2 twill weave pattern with a very precise mesh opening of 18 µm for air permeability. The open area of the fabric is 13%.

The commercially available, flexible paste ESL 1901-S (ESL Electroscience, U.S.A.) filled with silver particles was used for screen-printing the conductive silver electrodes onto the fabric substrate. The printed paste was cured at 125°C for 10 minutes in a hot air drier. This paste is referred to as silver paste.

Piezoresistive graphite paste from the Institute for Textile Chemistry and Fibre Chemistry (ITCF, Denkendorf, Germany) was used to obtain the piezoresistors. This paste is referred to as graphite paste and was printed between the silver electrodes, where some overlapping of the silver and graphite layers is required. The graphite paste was heated at 120°C for 3 minutes. The piezoresistor was printed at 0° with respect to the warp direction of the fabric. One, two and three layers of graphite paste, to obtain the piezoresistor, were printed. After each printed layer the sample was put into a hot-air drier to cure the layer.

The pattern for making the conductive electrodes and the piezoresistors was specially designed. The two silver electrodes are 23x7 mm rectangles, whereas the piezoresistor is a square of 10x10 mm. First the electrodes were printed, and after curing the piezoresistor was precisely positioned between the electrodes and printed.

The screen-printing technique was used to create the conductive electrodes and piezoresistors on the fabric. The screens were made from polyester cloth (Monolen) with a 75-µm mesh opening for the silver paste and a 183-µm mesh opening for the graphite paste. Both pastes were hand printed using a rubber squeeze with a hardness of 75 shores.

The mechanical properties of the fabric and of the fabric with the printed strain sensors were studied. The tests were made with a dynamometer (Instron 5567) according to the standard EN ISO 13934-1 (strip method). The testing device works on the constant-rate-of-extension (CRE) principle, where the rate of increase of the specimen length is uniform with time and the load-measuring mechanism moves a negligible distance with the increasing load [[[10]](#endnote-11)]. Five samples of the original filter fabric in the weft and warp directions were prepared with dimensions of 400x50 mm to evaluate the breaking strength and the tensile strain at maximum load. The as-prepared strips were then air-conditioned for 24 hours in a standard atmosphere (20°C ± 1°C, 65 % RH) and clamped between the jaws with a specimen length of 200 mm. The speed of the crosshead moving the upper jaw was set to 100 mm/min. The BlueHill® (Instron, United Kingdom) software testing package was applied for the tensile test control, data collection and result analysis. The Dinara software program (University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Textiles) [[[11]](#endnote-12)] was used to calculate the elastic region of the fabric.

For the evaluation of the electrical properties of the piezoresistor we bonded thin copper wires onto silver electrodes and connected them to a Keithley 2700 multimeter. The electrical resistance was recorded during the extension test performed on the dynamometer, as described before.

The gauge factor (GF) was calculated from the recorded data. The GF of a resistor, defined as the ratio of the relative change in resistance (ΔR/R) and the strain (ε), was calculated using Equation 1 [5].



(1)

The microstructure of the fabric and the deposited layers was examined using a scanning electron microscope FE-SEM SUPRA 35 VP (Carl Zeiss).

# RESULTS

Figure 1 shows the load-strain curves of the elastic region of the fabric in the warp direction and of the strain sensors with one, two or three layers of printed graphite paste.



Figure 1: Behaviour of the fabric and the fabric with the printed sensors in the elastic region

Figure 2a shows the printed strain sensor on the textile. The polyester fabric is printed with silver paste to make the electrodes and with carbon paste to make a thick-film piezoresistor. In Figure 2b a cross-section of the strain sensor is presented. The textile with the printed piezoresistive sensor is put into epoxy resin and then finely polished. The layers of silver and graphite paste are visible.

|  |  |
| --- | --- |
| **a.** | **b.** |

Figure 2: Printed strain sensor on the textile (a). Cross-section of the fabric with the printed sensor for a single layer of graphite paste (b).

Figure 3 shows the microstructure of the graphite layer deposited onto the fabric; Figure 3a shows 1 layer of graphite paste deposited on the fabric; Figure 3b shows two layers; and Figure 3c shows three layers of graphite paste deposited on the fabric.

|  |  |  |
| --- | --- | --- |
| **a.** | **b.** | **c.** |

Figure 3: SEM micrographs of one layer (a), two layers (b) and three layers (c) of graphite paste printed on the fabric

The piezoresistive properties of the sensors printed on the fabric were investigated. The sensors were subjected to a mechanical load from 0 to 20 N, which correlates with the elastic region of the fabric. Table 1 presents the change in the electrical resistance versus the strain in the elastic region for all three sensors, which differ in terms of the number of printed graphite layers. The calculated gauge factors (GFs) for all three sensors are also presented in Table 1.

Table 1: Resistance and gauge factor for a strain sensor with one, two and three layers of graphite paste

|  |  |  |  |
| --- | --- | --- | --- |
| **N° of graphite layer** | **R0 (Ω) at 0 % strain** | **R(Ω) at 1.5 % strain** | **Gauge factor** |
| 1 | 1905 | 2064 | 5.6 |
| 2 | 1100 | 1198 | 5.9 |
| 3 | 328 | 358 | 6.1 |

# DISCUSSION

Tensile tests were used to evaluate the strain of the fabric in the warp direction and of the printed strain sensors. The continuous curve from the measured data of load vs. elongation is presented in Figure 1. This test provided us with information about the behaviour of the fabric under load. The elastic behaviour of the fabric was evaluated to estimate the recovery of the fabric after removing the applied load. It was determined that the elastic region of the tested fabric ranges from 0% to 1.5% strain, and the load at 1.5% was below 20 N. Similar behaviour was observed for sensors with one, two or three layers of printed graphite paste. For the sensor with two and three layers of graphite paste a slightly larger load is required to cause strain than for sensors with one printed layer.

FE-SEM was used to evaluate the microstructure of the strain sensors printed with one, two or three layers (Figure 3). In the strain sensor with one printed layer the monofilament threads are finely covered with graphite paste and the textile’s structure is visible. After depositing a second layer of graphite paste the textile structure is still observed. When depositing three layers, a thick and flat coating is observed and the textile is covered with a continuous film.

A cross-section of the microstructure (Figure 2b) shows that the silver paste goes through the open areas of the threads and one layer of graphite paste is deposited on top of the silver paste. The thickness of the graphite paste is around 20–30 µm.

The electrical measurements were performed in the elastic region of the fabric to observe a change in the resistance for small strains. We observed an increase in the resistance for all three sensors. The resistance ranged from 350 Ω for the sensor with three layers up to 1900 Ω for the sensor with one layer. The change in the resistance is correlated with the changes in the thickness of the printed graphite layers and the deformations of the textile structure.

The relationship between the resistance and the strain is expressed by the gauge factor of the strain gauge sensor (Equation 1). This is a measure of the strain sensitivity. A sensor with one printed layer of graphite paste has a GF value of 5.6; a sensor with two layers has a value of 5.9; and a sensor with three layers has a GF value of 6.1.

# CONCLUSIONS

Piezoresistive strain sensors were integrated onto a textile substrate using screen-printing technology. The silver paste was used to obtain conductive electrodes, whereas the graphite paste was used to obtain piezoresistors. The number of graphite layers was varied from one to three, and the layers deposited on the textile exhibit a homogeneous structure. These layers surround well the filaments and the adhesion between fabric and the cured layers is good. With increasing the number of printed graphite layers a more continuous film is created. The performance of the strain sensors was evaluated by measuring their resistance changes under load, and this resistance was found to increase with increasing load. The gauge factor was calculated and had values ranging from 5.6 for a 1-layer graphite sensor, to 5.9 for a 2-layer sensor, and to 6.1 for a 3-layer sensor.

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