Thick-film strain sensor on textile

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ABSTRACT: In this paper preliminary investigations about integrating strain sensor based on thick-film strain gauge into fabric. When solid particles start to collect on the fabric, as a consequence of the clogging of the filter meshes, the pressure increases and this increase causes the deformation of the fabric. Strain sensor consists of carbon based piezoresistive layers terminated with silver conducting lines. Structure is realised by thick-film technology. Gauge factor of piezorestive sensor and microstructure of printed layers were determined.

1 INTRODUCTION

Smart textiles are becoming an emerging field of studies in last decades [1]. By integrating functional materials fore example piezoresistive, piezoelectric, piezocapacitive to flexible, lightweight, low cost, traditional textile substrates these materials are able to sense stimuli from the environment and response to the changes in certain predetermined manner [2].The potential use of piezoresistive effect as a sensing mechanism in a form of a strain gauge was studied on many materials [3]. First example of thick-film resistors used as strain gauge device was fabricated on ceramic diaphragm for pressure sensor applications.

Textile material is very flexible and can easily be deformed in all directions so the integrated sensor has to be able to follow these mechanical deformations [4]. Integrating the strain sensor into textile opens number of new applications which can serve as the basis for biomedical pressure monitoring systems [4] or could measure physical dimensions like pressure, stress and strain applied to the textile [5].Different approaches such as coating the fibre with piezoresistive material and fabricating electrodes by knitting, or weaving [6] the conductive fibres with non-conductive fibres, by wrapping fibres with conducting wires [1] were exploit. Inkjet printing of conductive lines [7] was also used to make sensors on textile. Flexible strain sensors to measure strain deformations were developed by printing conductive polymer composite (CPC) filled with carbon black powder to Nylon fabric [8]. Recently Mattmann et al. realised strain sensor to measure large strains (80 %) in textile mainly by attaching fibre-shaped sensor with silicone film to the textile [4]. Large area textiles sensors are used for sensing cracks in buildings due to earthquake or as smart carpets based on integrated pressure sensors [9].

Synthetic polyester filter fabrics are widely used for separating media because of high strength, dimensional and thermal stability, abrasion and acid resistance, hydrophobic nature and low cost production [10]. Filters used today are simple devices which act as a passive physical barrier without any other function.

The aim of our work is to make thick-film strain sensor on textile by screen printing technology

2 EXPERIMENTAL

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

Commercially available flexible paste ESL 1901-S (ESL Electroscience, U.S.A.) filled with silver particles was used for screen-printing of conductive electrodes and pads on fabric substrate. Printed paste was cured at 125°C for 10 minutes in hot air drier. After curing the silver paste must be flexible. The paste will be referred as silver paste (Ag paste).

The piezoresistive graphite paste from Institute for textile chemistry and fibre chemistry (ITCF, Denkendorf, Germany) was printed on silver electrode. The paste was heated at 120°C for 3 minutes in and will be referred as graphite paste (C paste).

Screen-printing technique was used to create piezoresistors on fabric. Screens were made from polyester cloth (Monolen) with 75 µm mesh opening for silver paste and 183 µm mesh opening for graphite paste. The choice of screen openings was made by recommendations of the paste suppliers and by our experiences to prevent clogging of the meshes. Both pastes were hand printed with the use of rubber squeeze with hardness of 75 shores.

Scheme of the pattern for making conductive electrodes, pads and piezoresistors was designed for testing strain sensor and is presented in Figure 1. The silver electrodes are 0.5 mm in width and silver pads are 3x3 mm. The dimensions of the piezoresistors are 3x3 mm. The resistors were printed in 0° according to the warp direction of the fabric.

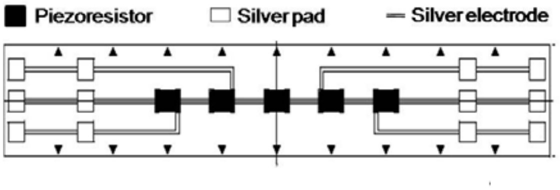

Figure 1: Scheme of the pattern for strain sensors.

The mechanical properties of the fabric and of the fabric containing the strain sensors have been studied. The tests have been done by dynamometer (Instron 5567) according to standard EN ISO 13934-1 (strip method). The testing device works on constant rate of extension (CRE) principle where the rate of increase of specimen length is uniform with time and the load measuring mechanism moves a negligible distance with increasing load [11]. 5 samples of origin filter fabric in weft and warp direction were prepared with the dimensions of 400x50 mm to evaluate breaking strength and tensile strain at max load. As prepared strips were air-conditioned for 24 hours in standard atmosphere (20°C ± 1°C, 65 % RH) and then clamped between the jaws with the specimen length of 200 mm. The speed of crosshead moving the upper jaw was set to 100 mm/min. BlueHill® (Instron, United Kindom) software testing package was applied for tensile test control, data collection and result analysis. Dinara software program (University of Ljubljana, Faculty of natural sciences and engineering, Department of Textiles) was used to calculate the elastic region of the fabric.

For evaluation of gauge factor of the piezoresistors we bonded copper thin wires onto silver pads and connected them to the multimetre apparatus Keithley 2700. Electrical resistance was recorded during the extension test performed on dynamometer as described before.

The gauge factor (GF) of a resistor defined as the ratio of the relative change in resistance (ΔR/R) and the strain (ε) was calculated by using Equation 1 [3].

$$GF = \frac{\Delta R/R}{\varepsilon} \qquad (1)$$

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

3 RESULTS AND DISCUSSIONS

Tension test was used to evaluate the strain of the fabric in warp and weft direction and obtained continuous curve from the measured data load vs. elongation is presented in Figure 2. This test provided us with useful information upon the behaviour of the fabric under load.

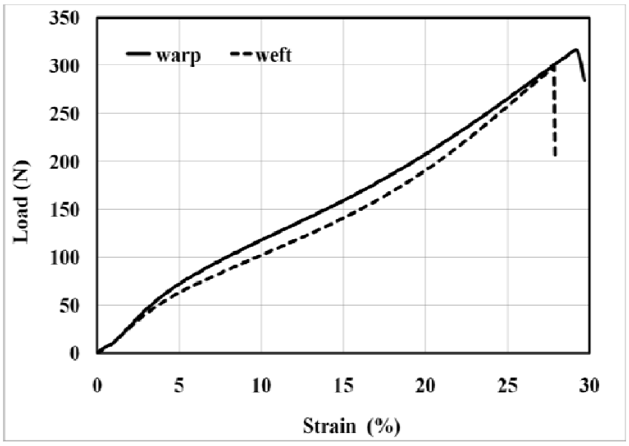

Figure 2: Load –strain curve of fabric in warp and weft direction.

The breaking strength of the warp and weft is 316 N and 298 N, respectively. Tensile strain at maximum load is 29% (58.3 mm) for warp and 28% (55.7 mm) for weft. 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 tested fabric ranges from 0% to 1.5% strain and the load at 1.5% is below 20 N.

More detailed evaluation of the elastic region of fabric in warp direction was performed. The fabric was subjected to load up to 20 N and the deformation of the fabric was measured. Comparison of the behaviour of fabric and fabric with the sensor at load up to 20 N is presented in Figure 3. Fabric shows almost linear dependence of load vs. strain, whereas at fabric with integrated sensor three regions are indicated. First region is form 0 to 0.1% strain and has the same slope as filter fabric. Second region presents a change in the slope, a steeper increase of load with strain is noted, meaning that for the unset of deformation higher load is needed. In the third region a similar behaviour as for filter fabric is noted but the deformation proceeds at higher loads, meaning that the fabric with the sensor will react similarly as the fabric under the action of tensile load, though at higher loads. This shows that sensor screen-printed onto the fabric alters the behaviour of the fabric in the elastic region; for deformation of fabric higher load is needed.

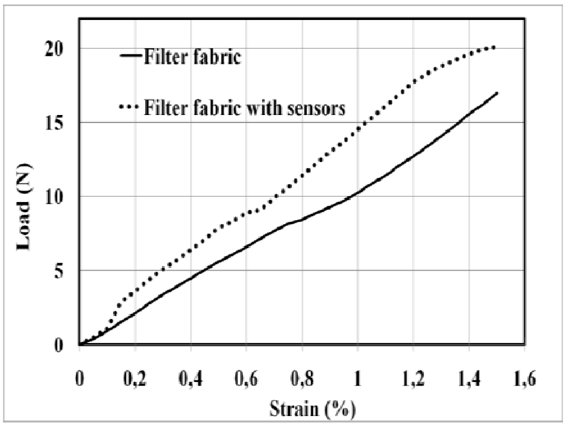

Figure 3: Behaviour of the fabric and fabric with sensors in elastic region.

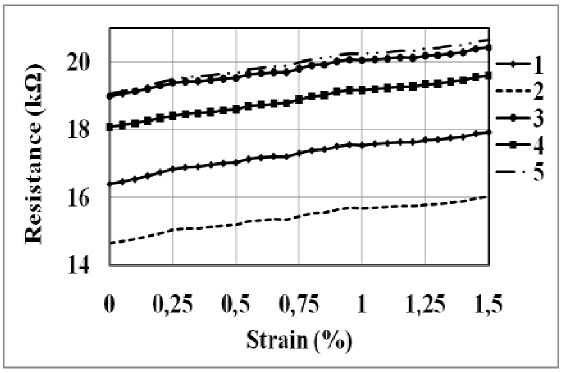

Figure 4: Change in electrical resistance versus strain for 10 piezoresistive sensors on the filter fabric.

Piezoresistive properties of sensor printed on the fabric were investigated. The sensors were subjected to predetermined mechanical load. Figure 4 presents the change in electrical resistance versus strain for all 5 sensors. The measurements were performed in elastic region of the fabric to observe change in resistance for small strains. We observe increase in resistance for all sensors in similar way. Resistance ranges from 14 kΩ for sensor 2 to 19 kΩ for sensor 5. The change in the resistance is correlated with the changes in the deformations of the textile structure.

The relationship between resistance and strain is expressed by gauge factor of the strain gauge sensor (Equation 1). It is the measure of strain sensitivity. The calculated gauge factors for all five sensors are presented in Table 1. Average value is around 5.

Sensor	GF
1	5
2	4,9
3	4
4	4,9
5	4

Table 1: Values of gauge factors for sensors.

Figure 5 presents silver electrode (a) on top of the fabric structure (b). Fabric structure is porous, between crossed weft and warp filaments pores of 15-20 µm are evident.

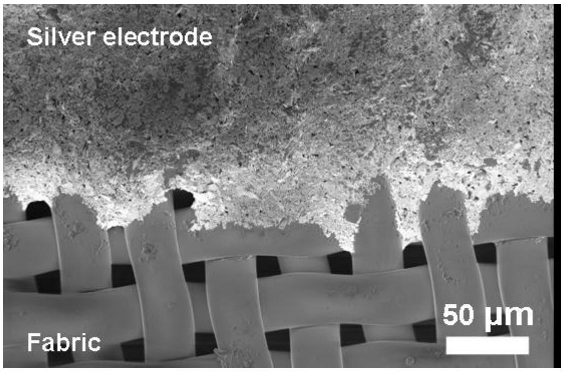

Figure 5: SEM micrograph of the silver electrode and fabric.

It is evident that the silver layer is fine grained and randomly distributed around the filaments. Adhesion between silver electrode and fabric is good.

Silver layer (Figure 6) consists of two types of particles which differ in shape and size. We can see flake type of particles raging from 4 – 12 µm in size. Second types of particles are spherical clusters of 2 – 4 µm in size. Silver is usually used in the form of small flakes in order to increase the contact area between the particles thus creating more paths for electrons to move and increase the conductivity [12]. The dark regions in between the particles indicate the porous structure.

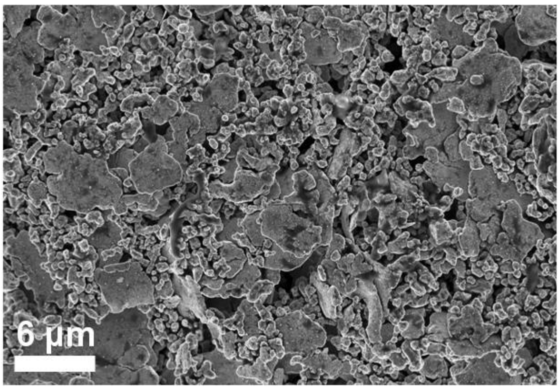

Figure 6: SEM micrograph of the surface of the silver layer.

Figure 7 shows graphite layer on the top of the fabric. We can observe that paste covered the fabric and open areas between the threads with continuous film.

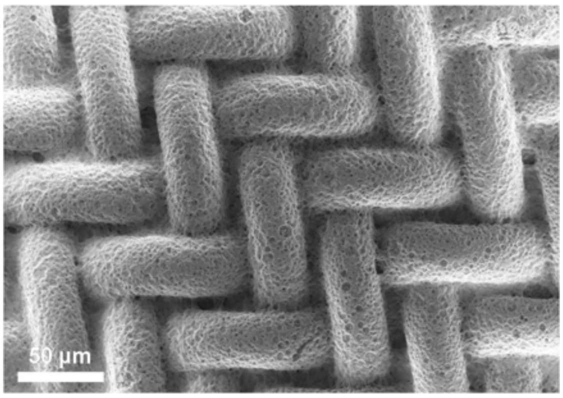

Figure 7: SEM micrograph of graphite layer on top of the fabric.

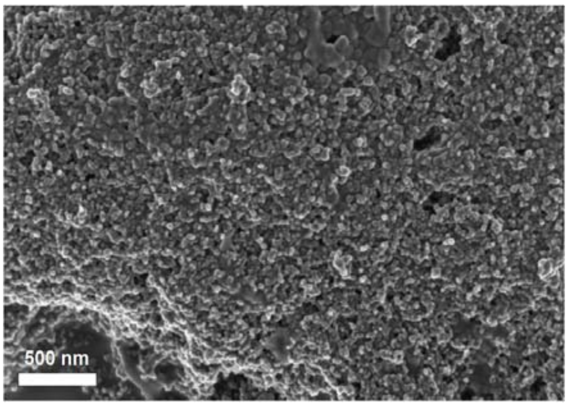

Figure 8: SEM micrograph of the surface of the C paste.

At higher magnification (Figure 8) we can observe spherical graphite particles in nanometre range. Some pores are present.

4 CONCLUSIONS

Piezoresistive strain sensors have been integrated into textile substrate by screen-printing technology.

The silver paste and graphite paste were used to print conductive lines and pads and piezoresistors. They consist of fine particles and exhibit homogeneous structure. They surround well the filaments and the adhesion between filter fabric and cured layers is good.

Performance of the strain sensor was evaluated by measuring their resistance changes under loading. Resistance increases with increasing load. Gauge factor was calculated and has the value of around 5.

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