Development of pressure sensors for smart textiles

P Gomes[1], D Tama[1,2], Y Yao[3], M J Abreu[1], A P Souto[1], H Carvalho[1]

[1] University of Minho, Center for Textile Science and Technology, Campus de Azurem, Guimaraes, Portugal
[2] Ege University, Department of Textile Engineering, 35100 Bornova / Izmir, Turkey
[3]University of Minho, School of Engineering, Dep. Industrial Electronics, Campus de Azurém 4800-058 Guimarães, Portugal

Corresponding author: vpcgomes@gmail.com

Abstract. The investigation of textile sensors has increased and has gained an important role in the creation of new solutions for the most varied products, from monitorization sensors, actuators and controllers, implemented in garments, house textile items, or textiles structures used for a specific purpose e.g. bridge structural monitoring, soil proprieties, among others. This paper presents the development of pressure sensors base in a conductive silicone with piezoresistive conductive properties. The objective is to explore the combination of different types of conductive material (conductive silicon, nonconductive silicon, conductive ink and conductive fabric) and test the interactions between them. In the production methods the conductive ink, and conductive fabric were fixed to the silicone in the curing phase. Conductive and nonconductive silicon were mixed to obtain better control of sample conductivity. Samples with different thicknesses were developed, it was study the influence on the voltage variation and conductivity for each sample.

Keywords. Pressure sensors, piezoresistive materials, conductive fabric, conductive ink, conductive silicone, e-textiles.

1. Introduction

Smart textiles using flexible integrated pressure sensors have many potential applications. In the medical field, these products may be used for measuring the pressure applied to the body via garments, namely, hosiery or bandages for varicose veins or leg ulcers [1,2] determining the suitability of a wheelchair cushion [3], monitoring the wearer's respiration [4]. In sports science, there are applications in martial arts to measure the impact [5-7] or monitoring the performance of muscles during exercise [8]. Also, in home automation objects with a textile base, is appearing an increase interest in creating new sensor and controller products [9].

Although there are different kinds of smart materials for sensor applications, the present study focused on building pressure sensors using piezoresistive materials.

Piezoresistive materials exhibit a change of electrical resistance when pressure is applied, enabling them to work as transducer material for sensors [3]. The development of flexible force sensors based on piezoresistive films was presented before. A copper tape, a ripstop conductive fabric and conductive knitted stretch fabric were used as electrodes and it has been found out that the different electrodes affect the sensor behavior [10].

In a previous study [11], Linqstat film was used as piezoresistive conductive polyethylene film. Conductive ink was used as electrodes and the adhesion of ink on plasma-treated piezoresistive film was analyzed, and the functionality of achieved sensors was evaluated. Pressure sensors were constructed as shown in Figure 1, using conductive fabrics as electrodes.

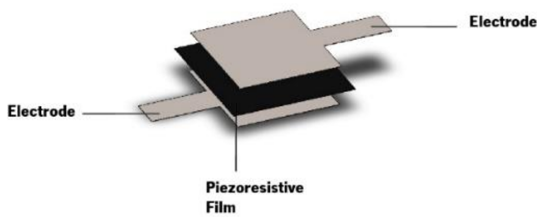


Figure 1. The construction of pressure sensors.

The current study aims at developing optimum pressure sensors for integrating into smart textile products.

2. Materials and Methods

2.1. Materials

In this study, pressure sensors were made by combining different materials. Conductive silicon (Wacker ELASTOSIL® LR 3162 A/B) was used as piezoresistive material. Linqstat film (Linqstat MVCF), conductive fabric (Silver plated polyamide fabric: Shieldex® Bremen), conductive ink (DuPont PE 825 Silver Composite Conductor, DuPont PE 828 Silver Conductor) and aluminum foil were used as electrodes. Wacker® primer G 790 was used to improve the adhesion between layers. Nonconductive silicone (Wacker Elastosil® LR 3003/50 A/B were also used.

2.2. Methods

Three different methods were used to produce the pressure sensors; high temperature curing, hot press and painting. In order to cure the conductive silicon, it has used a laboratory oven, and the temperature of 160ºC was applied for 10 minutes. The hot press technique, was used to create prototypes using Linqstat film and conductive silicon.

The sensor dimensions were (30 x 30) mm and the electrode dimensions were (25 x 25) mm. In order to improve adhesion of Linqstat on the silicon, a primer was added between the layers.The conductive inks were applied on the conductive silicon by brush painting technique. Two different conductive inks were used and applied in a (25 x 25) mm area of the sensor. The curing conditions of PE 825 was 120°C, 10minutes and the curing conditions of PE 828, which was more flexible, was 80°C, 20 minutes in the oven.

The conductive fabric and conductive silicon sensor was put together during the curing process at 160ºC for 10 minutes. Plasma treatment was applied in the conductive silicon samples to increase the adhesion properties of the material. All the sensors developed were tested using a Hounsfield dynamometer producing 10 cycles of compression between 2 and 100 N at a speed set at 5 mm/min. Figure 2 shows the setup for the cyclic compression test. Encapsulation is achieved using 2mm-thick EPDM foam, which conveys mechanical protection to the sensing element.

The sensor was connected to a Fluke 45 multimeter that acquires resistance values and transmits them to a PC via RS-232. In a second trial, the sensor was connected to a signal conditioning circuit that produces a voltage signal according to the sensor's resistance, as depicted in Figure 2.

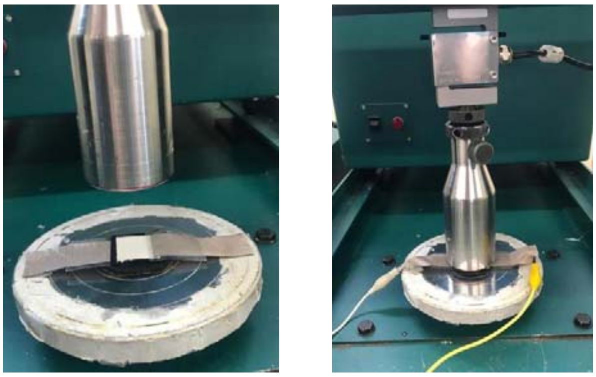


Figure 2. Compression test setup.

3. Results

3.1. Piezoresistive Silicon

To create the pressure sensor, firstly the piezoresistive material must be obtained. Therefore, the inner part was produced, conductive silicone was prepared using "ELASTOSIL-LR-3162, A/B". It was prepared using A and B compounds according to the mixing ratio 1:1. The curing condition of this silicone is 160°C, 10 minutes.

Firstly, bare silicone samples were prepared in order to determine conductivity. After preparing the mixture, it was used a coating machine to obtain an even sample with 2 mm thickness (Figure 3).

Figure 3. Silicone sample from coating machine.

During curing process, the silicone swells and bubbles emerged on one side's surface of sample, which contacts with air. In order to overcome that problem, it was decided to use a different method, the mixture was compressed between 2 glasses and cured (Figure 4).

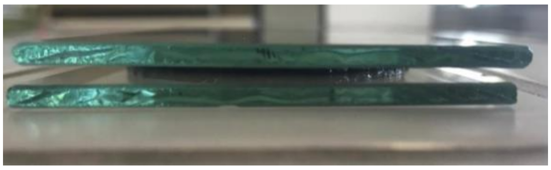


Figure 4. Silicone sample by squeezing between 2 glasses.

In order to obtain a specific form, a mask (Figure 5) was used between the glasses to shape the silicon in different forms.

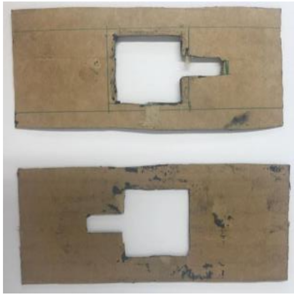


Figure 5. Mask used for the sample with linqstat and conductive silicone.

By this method, an even surface was obtained. When the conductivity was analyzed, we determined that the silicone has high conductivity and behaves like a piezoresistive material.

3.2. Linqstat and conductive silicon sample

In order to make the silicone and linqstat film connection, it was used the hot press method. Firstly, it was used the hot press at 120°C, for 10 seconds, and the pressure of the plates were set to 3,5 bars. The sample were checked, but the silicone didn't show adhesion to the linqstat film. Therefore, the condition was changed to 125°C, for 30 seconds. After that process, the linqstat film was melted and destroyed (Figure 6).

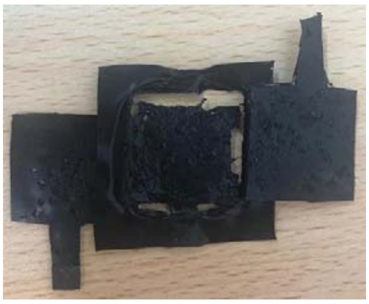


Figure 6. Destroyed sample prepared by hot press.

To obtain a better adhesion, it was used a primer (WACKER® PRIMER G 790. The primer serves as adhesion promoter between silicone elastomers and other substrates like metals, glass and thermoplasts. The primer was applied on the linqstat by spraying method. The same conditions were applied in the hot press machine (120ºC, 10 minutes) but the conductive silicone doesn't stick on the velostat even when the primer is used. By these tests, is possible to ensure that, isn't possible to obtain a working sample with linqstat and conductive silicone, so other methodologies had to be tested.

3.3. Conductive ink and conductive silicon sample

The samples were prepared using both PE 825 (Figure 7) and PE 828 (Figure 8), the conductive inks were applied on silicone by brush. The curing conditions were 120°C, 10 minutes for PE 825 and 80°C, 20 minutes for PE 828. The samples presented cracks and bad adhesion between the inks and the silicon.

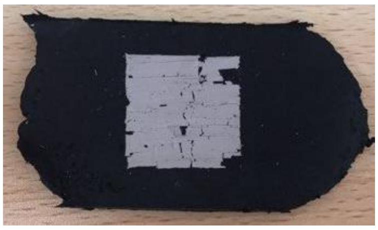


Figure 7. Sample with conductive silicone and PE 825 conductive ink.

Figure 8. The sample with conductive silicone and PE 828 conductive ink.

In order to improve the bonding properties plasma treatment can be used to induce surface texturization (creation of microroughness) increasing the possibility to get a better absorption and adhesion of finishing agents, stamping, inks. The process may induce secondary reactions such as crosslinking thus allowing graft polymerization. Therefore, plasma treatment was applied on the conductive silicone. This treatment was inefficient due to the high conductivity of the silicon material, that didn't allow the generation of plasma in the plasma machine. It was concluded that, the conductive ink isn't appropriate for using with conductive silicone.

3.4. Conductive fabric/aluminium foil and conductive silicon sample

As determined before the conductive silicone sample created behaves like piezoresistive material, it was prepared a sensor with conductive silicone and conductive fabric. We used the glasses to press the silicon and a mask in order to have the sample in desired dimensions (Figure 9).

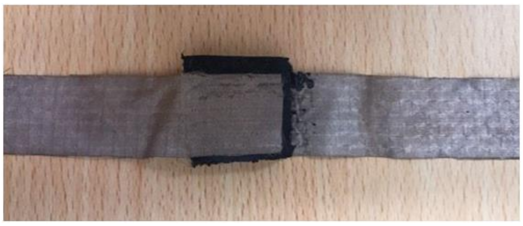


Figure 9. Sensor with conductive silicone and conductive fabric.

The sample didn't work as a sensor, it seems it has a short circuit. For that reason, we decided to prepare a sample using aluminum foil instead of conductive fabric, which is well known high conductive material (Figure 10).

Figure 10. Sensor with conductive silicone and aluminum foil.

The same process for preparing the sample was used. After the tests the results showed that the sample works as a sensor.

3.5. Different conductivity silicon samples

In order to improve the signals inputs and the construction of the sensors, different mixtures, and different thicknesses were made to determine the possibility to change the conductivity in the silicon, and the influence of each parameter in the final results. The conductive silicone was mixed in 90%, 80% and 50% rate with nonconductive silicon, they cured at 160ºC for 10 minutes.

After preparing the samples they were tested in 10 cycles of compression between 2 and 100 N force in the Hounsfield dynamometer and the data were collected. It was analysed the force vs extension behaviour of the sample (Tables 1, 2 and 3).

The graphics present a small deviation for all the samples, in an ideal graphic for force and extension, the lines should overlap in every cycle. These results present a loss in recovering capacity in every cycle. The samples of 80% conductive silicone and 20% nonconductive in all thicknesses had the worst performance presenting the greatest dispersibility.

The samples were also analysed for changes in the resistivity during the 10 cycles test (Tables 4, 5 and 6).

As it could be seen the samples conductivity vary with the changes in the concentrations and thickness. The resistance increases with the increases of nonconductive material. In the 1mm samples (Table 4) the variation in resistivity is to low, turning it not suitable for sensor application.

Table 1. Silicon samples 1mm thickness - force vs extension.

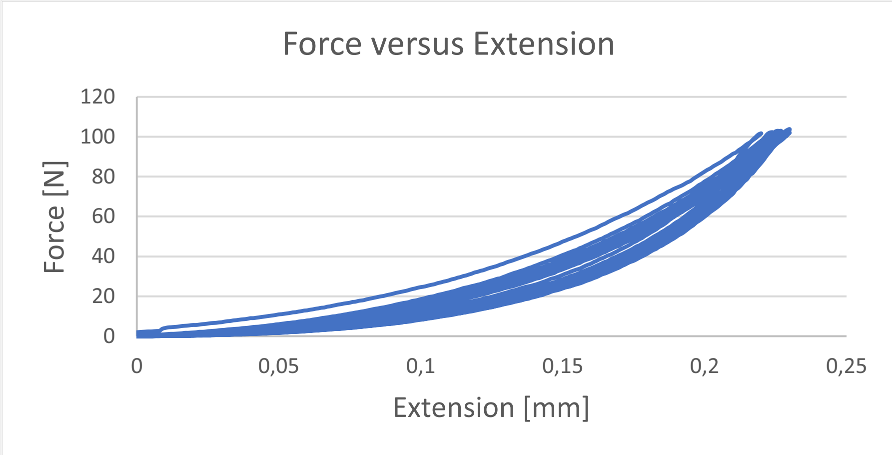
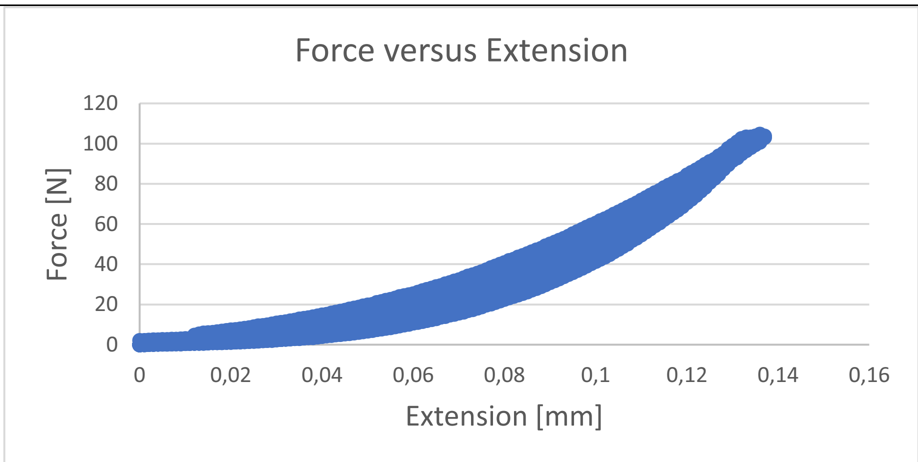
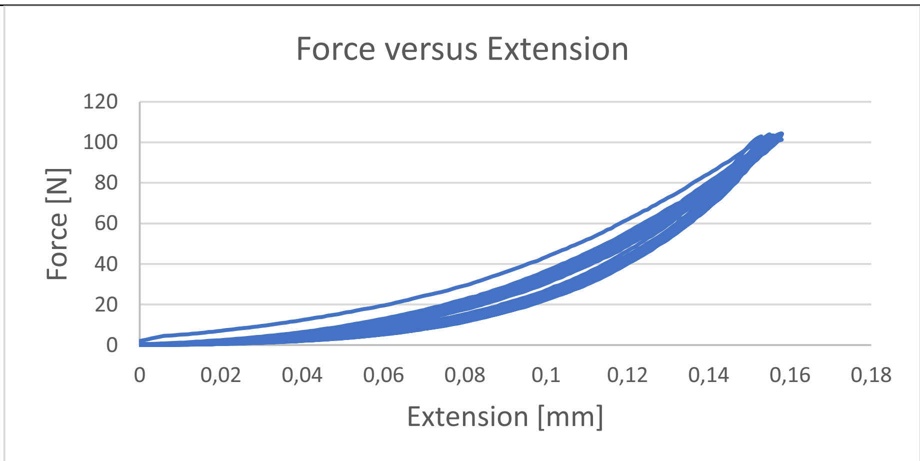
<table>
<tr><td></td><td>1 mm</td></tr>
<tr><td>90% Cond. Silc - 10% Non-cond. Silc.</td><td>
</td></tr>
<tr><td>80% Cond. Silc - 20% Non-cond. Silc.</td><td>
</td></tr>
<tr><td>50% Cond. Silc - 50% Non-cond. Silc.</td><td>
</td></tr>
</table>

Table 2. Silicon samples 2mm thickness - force vs extension.

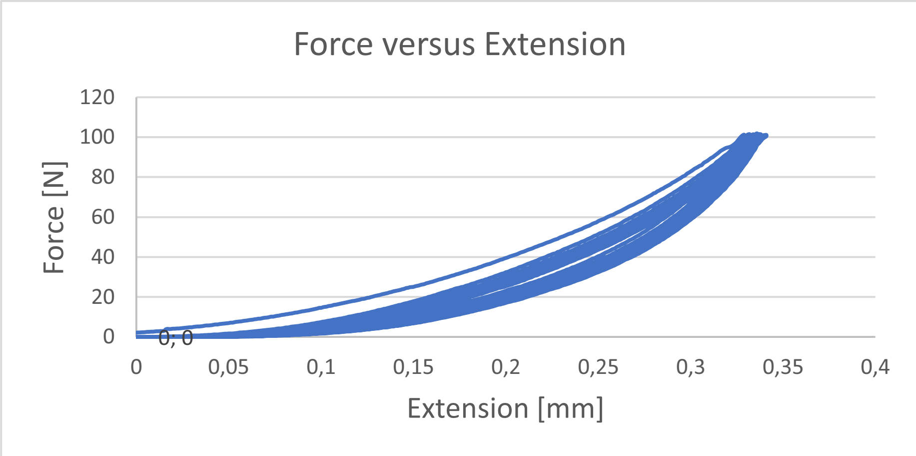
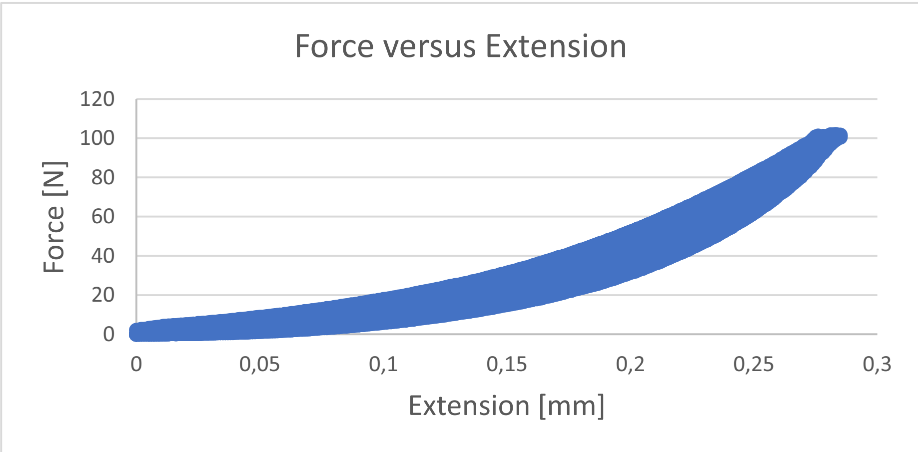
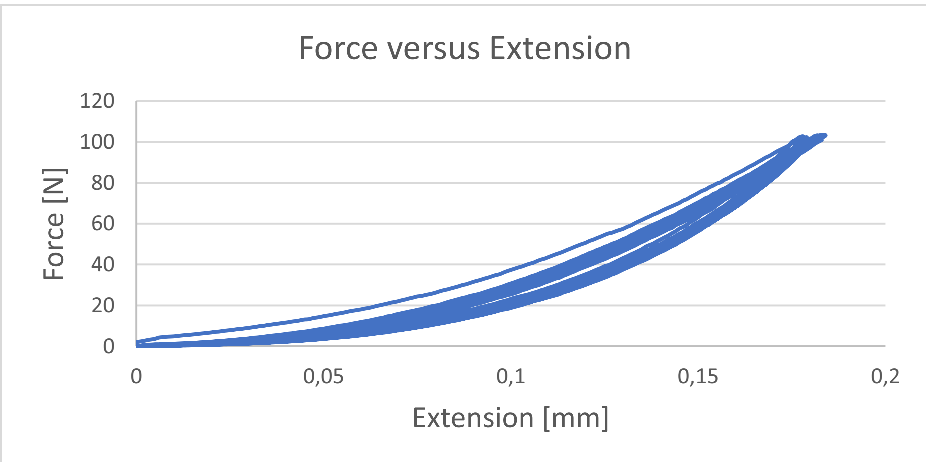
	2 mm
90% Cond. Silc - 10% Non-cond. Silc.	
80% Cond. Silc - 20% Non-cond. Silc.	
50% Cond. Silc - 50% Non-cond. Silc.	

Table 3. Silicon samples 3mm thickness - force vs extension.

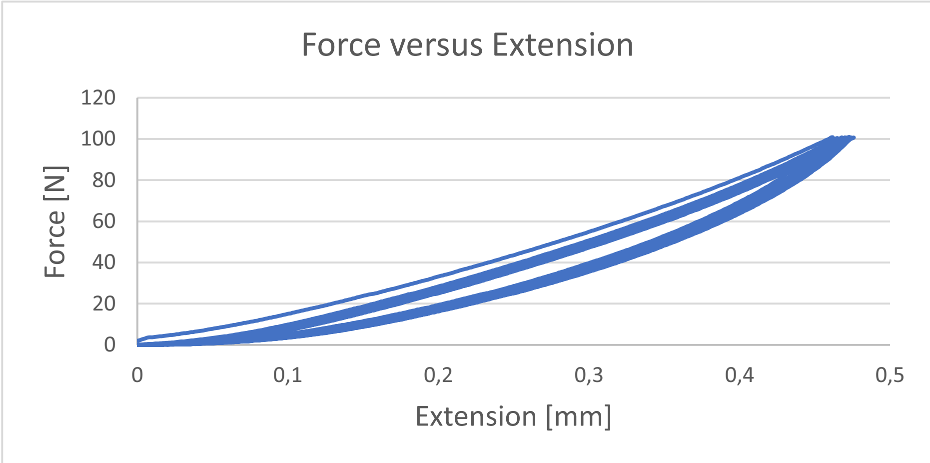
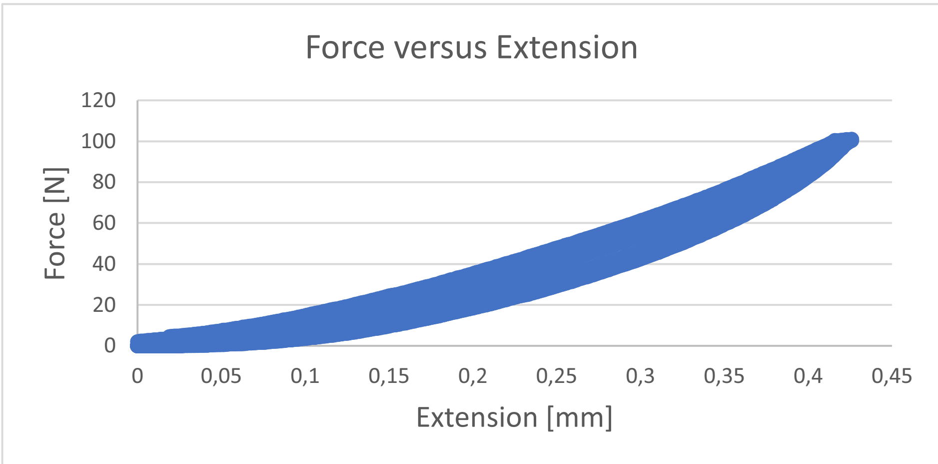
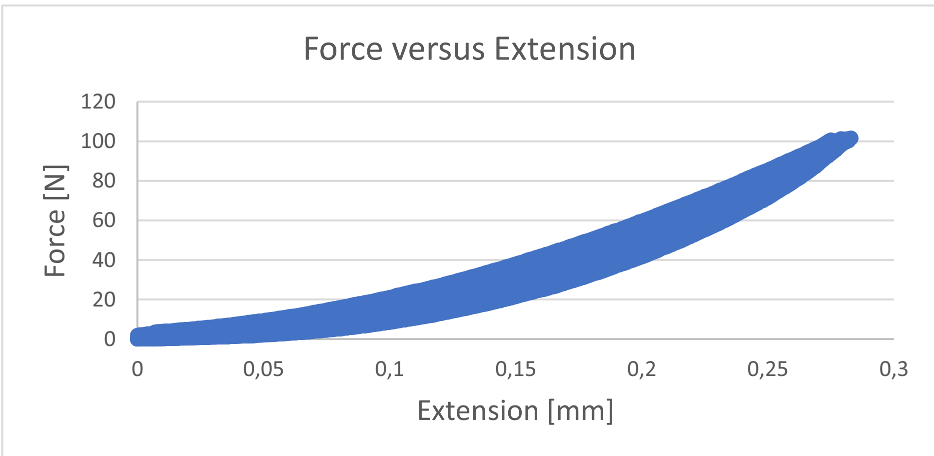
	3 mm
90% Cond. Silc - 10% Non-cond. Silc.	
80% Cond. Silc - 20% Non-cond. Silc.	
50% Cond. Silc - 50% Non-cond. Silc.	

Table 4. Silicon samples 1mm thickness - resistance vs time.

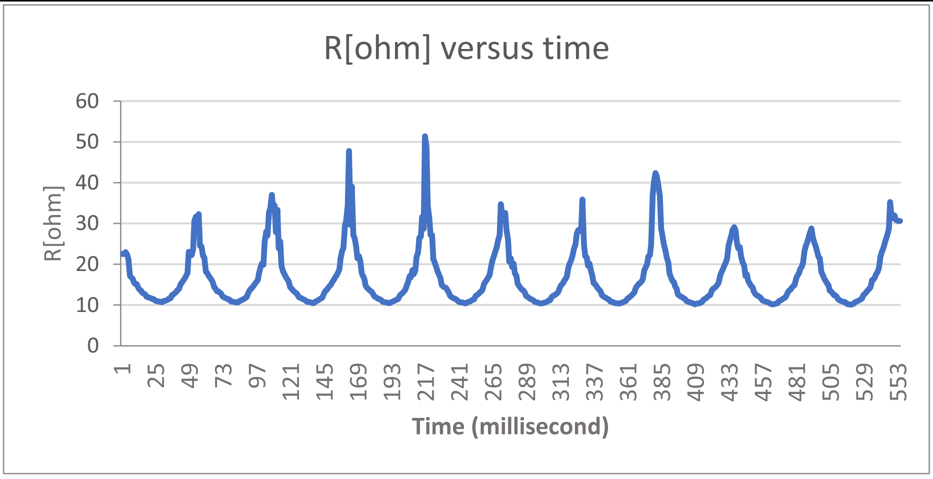
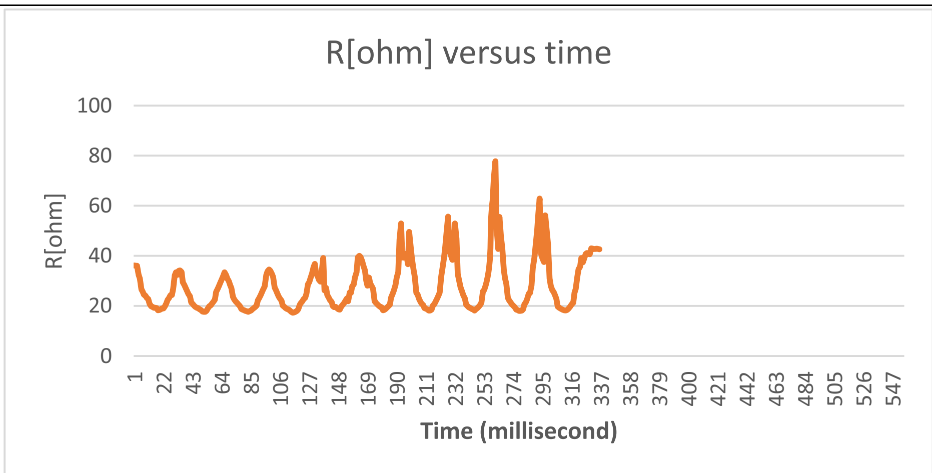
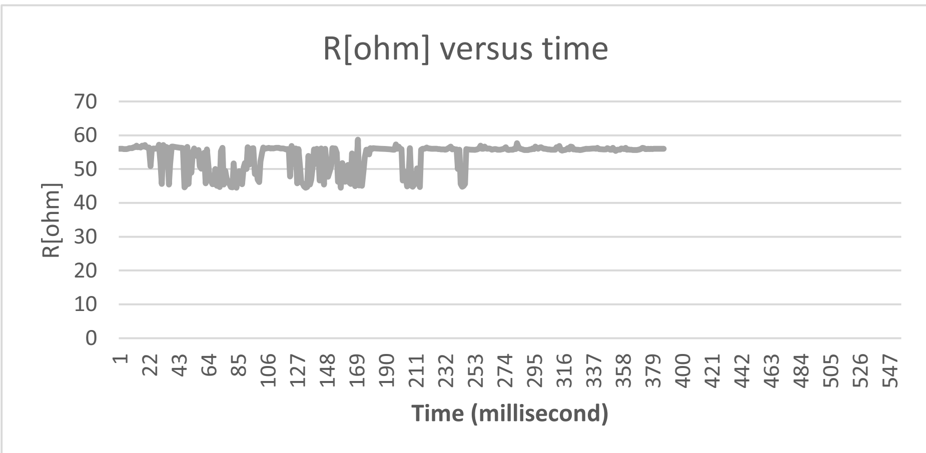
	1 mm
90% Cond. Silc - 10% Non-cond. Silc.	
80% Cond. Silc - 20% Non-cond. Silc.	
50% Cond. Silc - 50% Non-cond. Silc.	

Table 5. Silicon samples 2mm thickness - resistance vs time.

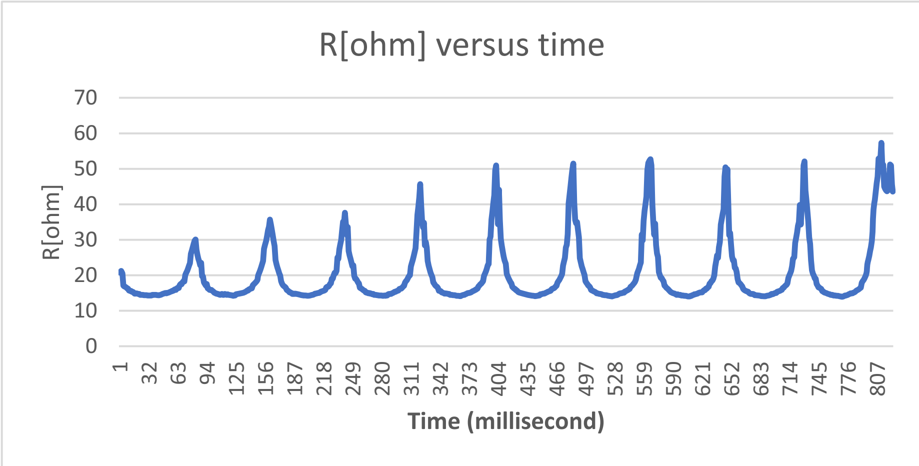
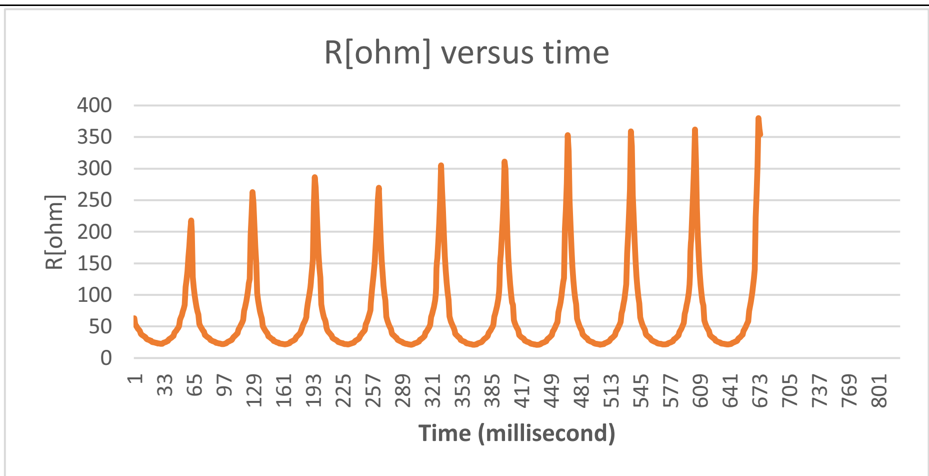
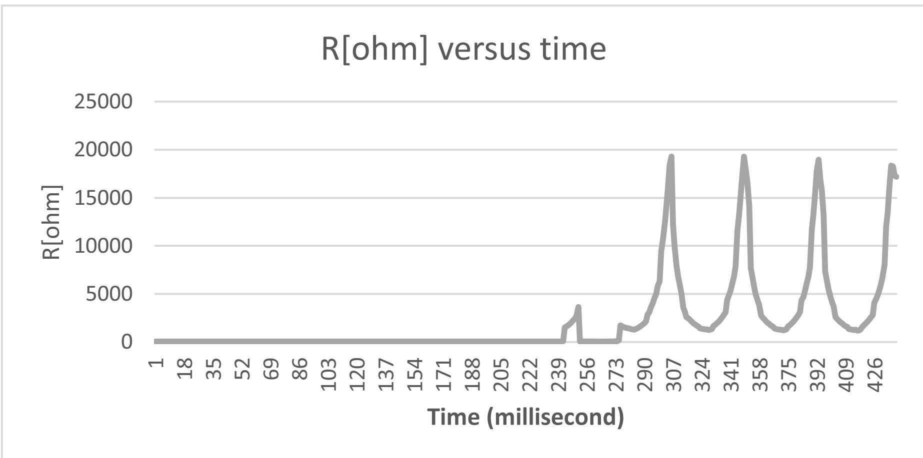
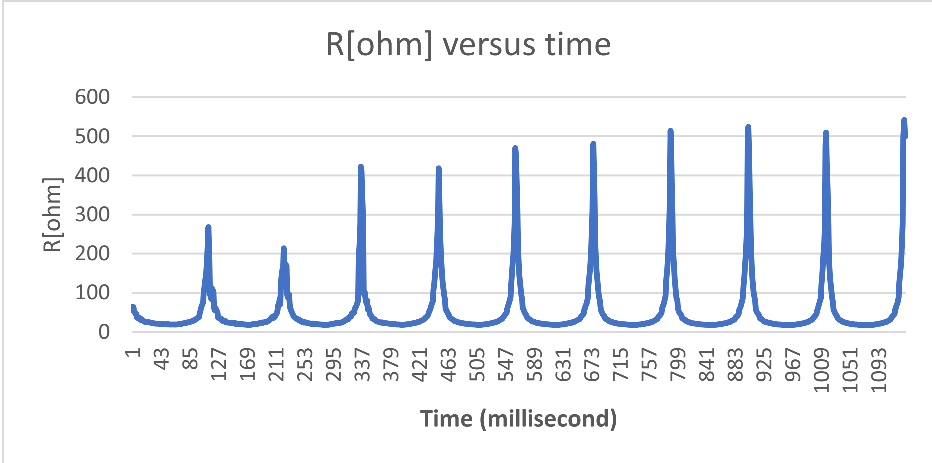
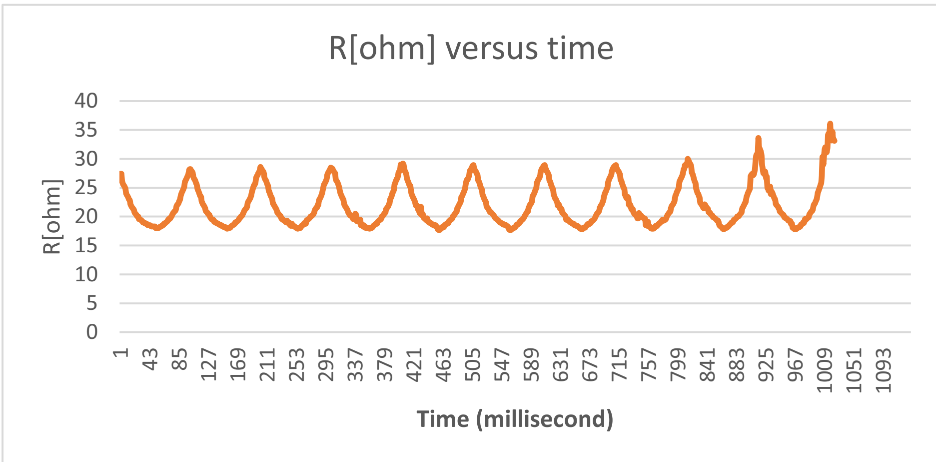
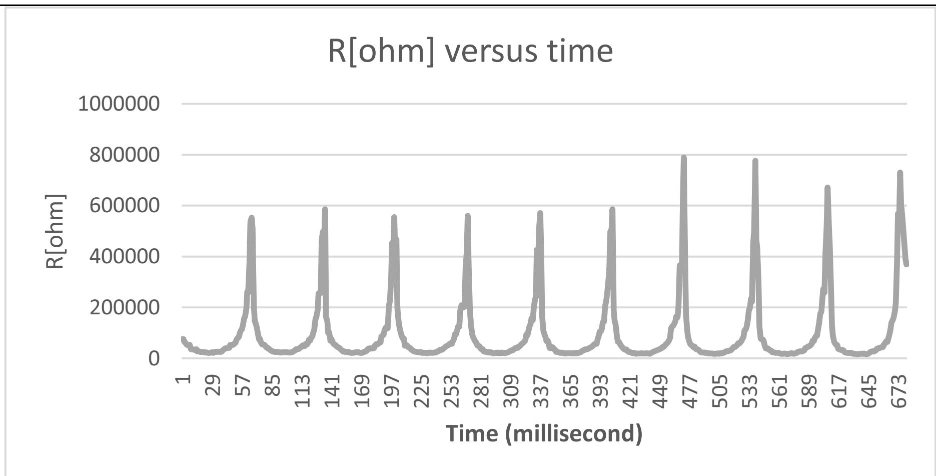
<table>
<tr><td></td><td>2 mm</td></tr>
<tr><td>90% Cond. Silc - 10% Non-cond. Silc.</td><td>
</td></tr>
<tr><td>80% Cond. Silc - 20% Non-cond. Silc.</td><td>
</td></tr>
<tr><td>50% Cond. Silc - 50% Non-cond. Silc.</td><td>
</td></tr>
</table>

Table 6. Silicon samples 3mm thickness - resistance vs time.

<table>
<tr><th></th><th>3 mm</th></tr>
<tr><td>90% Cond. Silc - 10% Non-cond. Silc.</td><td>
</td></tr>
<tr><td>80% Cond. Silc - 20% Non-cond. Silc.</td><td>
</td></tr>
<tr><td>50% Cond. Silc - 50% Non-cond. Silc.</td><td>
</td></tr>
</table>

The 2mm samples (Table 5) presented a uniform behaviour increasing the resistivity values with the increase of nonconductive material.

The 3mm samples (Table 6) presents an increase in resistivity when compared with 2mm samples for the same values (90% and 50% conductive material). The 80% conductive sample presented a low value of resistance and low oscillation in the values.

4. Conclusion

A piezoresistive material could be obtained by using conductive silicon. The thickness can be adjusted in the process of high temperature curing using a compressing technique. This technique prevents the expansion of the silicon and the formation of bubbles inside the sample. Silicon did not present good adhesion properties to conductive ink and the linqstat, turning it impossible to use them as electrodes, even with the application of primer. A linking was established with conductive fabric and aluminum foil during the curing phase. Although the adhesion the conductive fabric prevents the silicon to act as a piezoresistive material, the aluminum foil was a god electrode. Mixing nonconductive material to the conductive silicon is possible in order to control the resistance values. In further studies new samples will be prepared and tested with new material to improve the adhesion and prevent the short cutting with the conductive fabric. Different thickness samples and different concentration of conductive and nonconductive material will be tested in order to determine the values of resistance that is possible to obtain for the creation of pressure sensors.

Acknowledgment

This work is financed by FEDER funds through the Competitivity Factors Operational Program - COMPETE and by national funds through FCT – Foundation for Science and Technology within the scope of the project POCI-01-0145-FEDER-007136. Derya Tama thanks FCT for fellowship 2C2T-BPD-08-2017.

References

[1] Macintyre, L., 2011, New calibration method for I-scan sensors to enable the precise measurement of pressures delivered by ‘pressure garments’, Burns, Vol:37, pp. 1117 –1181.

[2] Baldoli, I., Mazzocchi, T., Paoletti, C., Ricotti, L., Salvo, P., Dini, V., Laschi, C., Francesco F.D. and Menciassi, A., 2016, Pressure mapping with textile sensors for compression therapy monitoring, Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine, Vol 230, Issue 8, pp. 795 – 808, https://doi.org/10.1177/0954411916655184

[3] Bosowski, P., Hoerr, M., Mecnika, V., Gries, T. and Jockenhövel, S., 2015, Electronic Textiles, Smart Fabrics and Wearable Technology: Design and manufacture of textile-based sensors, Woodhead Publishing, England, 307 p.

[4] Brady, S., Dunne, L. E., Tynan, R., Diamond, D., Smyth, B. and O’Hare G. M. P., 2005, Garment-Based Monitoring of Respiration Rate Using a Foam Pressure Sensor, Ninth IEEE International Symposium on Wearable Computers (ISWC'05), 2005, pp. 214-215, doi: 10.1109/ISWC.2005.23

[5] Cowie, J. I., Flint, J. Z. and Harland, A. R., 2009, The Engineering of Sport: Wireless Impact Measurement for Martial Arts, Springer, France, 713p.

[6] Del Vecchio, F.B., Franchini, E., Del Vecchio, A.H.M. and Pieter, W., Energy absorbed by electronic body protectors from kicks in a taekwondo competition, Biology of Sport, 2011,Vol. 28(1).

[7] Mcloughlin, J., Cashman, P., Power, J. and Ledbury, J., A Smart Textile for Measuring the Impact of Energy used in Competitive Contact Sports’, The Textile Institute International Conference: Advances in Functional Textiles, 25 26th July 2013, Manchester, UK. (Unpublished), retrieved 10/06/2017 fromhttp://eprints.hud.ac.uk/id/eprint/18533/3/28_A_Smart_textile_for_measuring.pdf

[8] Zhou, B., Sundholm, M., Cheng, J., Cruz, H. and Lukowicz, P., 2016, Never skip leg day: A novel wearable approach to monitoring gym leg exercises, 2016 IEEE International Conference on Pervasive Computing and Communications (PerCom), Sydney, NSW, pp. 1-9, doi: 10.1109/PERCOM.2016.7456520

[9] Ojuroye O., Torah R., Beeby S., Wilde A. (2017) Smart Textiles for Smart Home Control and Enriching Future Wireless Sensor Network Data. In: Postolache O., Mukhopadhyay S., Jayasundera K., Swain A. (eds) Sensors for Everyday Life. Smart Sensors, Measurement and Instrumentation, vol 22. Springer, Cham, DOI; https://doi.org/10.1007/978-3-319-47319-2_9

[10] Carvalho H., Yao Y. and Gonçalves M., 2017, Flexible force sensors for e-textiles, 17th World Textile Conference AUTEX 2017- Textiles - Shaping the Future, Conf. Series: Materials Science and Engineering 254 (2017) 072007 doi:10.1088/1757-899X/254/7/072007

[11] Tama, D., Gomes, P., Yao, Y., Abreu, M.J., Souto, A.P. and Carvalho, H., 2017, Developing Smart Body Protector for Sports Karate, XIVth International Izmir Textile & Apparel Symposium (IITAS 2017), Izmir, October 26-28.