Polymer-Based Flexible Strain Sensor

Fernando Martínez,*, Gregorio Obieta, Ion Uribe, Tomasz Sikora, Estibalitz Ochote

*Sensors Department, Ikerlan-IK4 Technological Research Centre, Mondragon, Spain
New Materials Department, Cidetec-IK4, San Sebastian, Spain

Abstract

The design and characterization of polymer-based flexible strain sensors is presented. Characteristics as lightness and flexibility make them suitable for the measure of strain. Several sensors have been realized to analyze the influence of size and electrical conductivity on their behavior. Elongation and applied charge have been precisely controlled in order to measure different parameters as electrical resistance, gauge factor (GF), hysteresis and repeatability. The results clearly show the influence of size and electrical conductivity on the gauge factor, but it is also important to point out the necessity of controlling the hysteresis and repeatability of the response for precision demanding applications.

Keywords: strain sensor; flexible sensor; electrical conductivity; gauge factor.

1. Introduction

Technological advances and the need of new services, require the development of new resources and materials. These resources and materials must be designed to improve the security and insure the well-being of people. Nowadays, there is an increasing tendency of developing smart sensors based on flexible materials capable of cutting down the structural restrictions of conventional sensors as it is shown in [1] and [2]. These new materials are known as smart materials because of their ability to react to outside signals and to communicate with control elements. They have been designed to be used in fields as people’s rehabilitation and health monitoring, in applications that require incorporating the sensors to the textile as it is shown in [3]. Applications for the measurement of biological signals (electrocardiogram, breathing, joint position and movements, skin temperature …) could be developed by different devices implementation (woven or knitted metal electrodes, EAP based textile fibers or small-size strips, optical fibers …). Due to mechanical restrictions the integration of conventional strain gauges in flexible structures is difficult. Some materials, such as conductive elastomers are very flexible and easy to deform, and could be used as sensors having the ability to be integrated in such structures without changing their behavior.
2. Experimental

2.1. Sensor Material

Elastosil® LR 3162 A/B, from WACKER Ltd, was the selected material for the production of the sensors. It is an electrically conductive liquid silicone rubber with good mechanical, electrical, ageing and fast vulcanization properties that make it very attractive for its application in sensors.

It has a density of 1.12 g/cm³ at 23 °C, a viscosity of 6500 Pa·s, a tensile strength of 5.4 N/mm², 410 % of elongation at break, a tear strength of 12 N/mm and a volume resistivity of 11 Ω·cm. The material requires 10 minutes at 165°C, under pressure, as cure condition.

The electrical properties of polymeric composites are highly dependent on volume, distribution, size, shape, phase orientation and interaction with the added conductive fillers. The electric charges create electrical pathways, and there is a transition of the material from electrically insulating to conductive. An appropriate loading level for the conductive fillers is needed, to establish a compromise between desired physical and electrical properties. If the elastomer were highly loaded to reduce the resistivity, the material would become too hard and would exhibit lower elongation and tensile strength. Different filler contents have been tested to obtain the required electrical and mechanical characteristics.

Based on Elastosil® and carbon nanotube fillers, three different electrical conductivity sensors have been realized: 0.1 mS/cm, 2 mS/cm and 5 mS/cm. Furthermore, different sensor sizes have been analyzed: length from 33 mm to 96 mm and width between 9 mm and 20 mm.

2.2. Sensor Characterization System

The produced sensors were characterized through multiple elongation-contraction cycles, using a strain tester. This device was composed of a traction instrument and a measurement system for data acquisition, where the number, velocity and elongation of the cycles could be configured dynamically. This automation allowed to complete multiple elongation-contraction cycles to characterize the material. Different parameter configurations were performed, depending on the mechanical properties of the characterized sensor materials (size, elongation at break, tear strength…). Parameters of velocity (0.001 m/s up to 0.01 m/s) and elongation cycles were chosen related to the applications where the materials were being to be used.

3. Results and Discussion

In this section, the results after sensor characterization are shown. For sensor characterization purposes different properties have been studied: the dependence of the electrical resistivity with sensors size, elongation and electrical conductivity, the gauge factor, the hysteresis, the linearity and the repeatability. Apart from a gauge factor or sensitivity adapted to the application [4, 5], it is necessary to obtain a good linearity, repeatability and a controlled hysteresis in the material response.

3.1. Electrical Resistivity

Different conductivity sensors were cycled up to 25-30% elongation. The elongation of the sensor produces a decrease in the number of electrical connections between the conductive particles in the material, causing the increase of the resistance. Figure 1(a), shows this fact, where, for every sensor, the working electrical resistance increases as the elongation increases. Furthermore, for a certain elongation percentage, the absolute increment of electrical resistance is lower for higher electrical conductivity materials.
The gauge factor is the parameter used to define the sensitivity of the sensor. It measures the change of electrical resistance regarding to material deformation.

![Electrical Resistance Variation vs Elongation for different conductivities](image)

Fig. 1. (a) Electrical Resistance (KΩ) vs. Elongation (mm) for different electrical conductivity elastomers; (b) Electrical Resistance Variation (%) vs. Elongation (%) for different electrical conductivity elastomers.

As Figure 1(b) shows, the gauge factor is not directly proportional to the electrical conductivity. The higher value is obtained for the 2 mS/cm intermediate electrical conductivity sensor.

In every sensor, the response is not totally linear. There are regions were the response is non-linear, what can be explained as a change in geometrical structure by the influence of multiple strain cycles, caused by a remaining elongation. It is advisable to have a suitable sensitivity value, but with a linear sensor response in the desired working range.

3.2. Repeatability

Repeatability refers to the capacity of the sensor to provide the same response, for the same input signal, keeping constant the measurement conditions. This property ensures the availability of the sensor for a long period of time and the validity of obtained measures. In this work, the repeatability between different cycles has been measured.

![Electrical Resistance vs Elongation for 2mS/cm Elastomer](image)

Fig. 2 (a). Deviation between measured elongation cycles; (b) Hysteresis between measured elongation-contraction cycles

Figure 2(a) shows the characterization of multiple cycles, and the deviation between them. The best obtained value is a deviation of 3.26% of the elongation cycle, for an elongation of 26% of the elastomer initial length. This value is obtained for the 2 mS/cm of electrical conductivity sensor. It is considerably better than the value obtained for the sensor of 0.1 mS/cm of electrical conductivity, a deviation of 6.56% of the elongation cycle, for an elongation of 22% of the elastomer initial length. And it is also better than the deviation value obtained for the 5
mS/cm of electrical conductivity sensor, a deviation of 4.5% of the elongation cycle, for an elongation of 27% of the elastomer initial length.

3.3. Hysteresis

Hysteresis comes out in systems where the output does not only depend on the input, but it also depends on the history of the input. In Figure 1(b), the hysteresis in multiple measured elongation cycles is shown. This effect causes the difference between the sensor response during elongation and contraction. The best value is obtained for the sensor of 2mS/cm of electrical conductivity, 14% of maximum hysteresis for an elongation of 26% of the elastomer initial length. It is considerably better than the one obtained for 0.1 mS/cm of electrical conductivity sensor, a maximum hysteresis of 38% for an elongation of 26% of the elastomer initial length. And it is also better than the hysteresis obtained for 5 mS/cm of electrical conductivity sensor, a maximum hysteresis of 20% for an elongation of 27% of the elastomer initial length.

4. Conclusions

The design and characterization of polymer-based flexible strain sensors have been presented in this paper. The behavior of sensors, in terms of dimensions and electrical conductivity, has been studied, under multiple elongation-contraction cycles, carried out in a strain tester. Elastosil® was the selected material due to its properties that make it appropriate to be integrated in flexible structures. Different sensor characteristics have been analyzed: physical characteristics, as electrical conductivity and dimensions, and working characteristics, as gauge factor, linearity, hysteresis and repeatability. The influence of size, elongation and electrical conductivity on the sensitivity of the sensor has been demonstrated. A good sensitivity value, adapted to the application, is very important, but it is not less important to have a linear response, a good repeatability and a low hysteresis factor.

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