Northumbria Research Link

This version was downloaded from Northumbria Research Link: http://nrl.northumbria.ac.uk/id/eprint/34003/

Northumbria University NEWCASTLE

UniversityLibrary

ELSEVIER

Proceedings of the Eurosensors XXIII conference

Porous PDMS force sensitive resistors

M.G. King, A.J. Baragwanath, M.C. Rosamond, D. Wood and A.J. Gallant*

School of Engineering, Durham University, South Rd, Durham, DH1 3LE, UK.

Abstract

Here we present an elastomeric force sensitive resistor (FSR) made from a porous matrix of polydimethylsiloxane (PDMS) filled with carbon black. The fabrication process is based on the use of a low cost sacrificial sugar cube scaffold which leads to a highly porous and compressible material. By filling this porous matrix with carbon black we can achieve typical resistance changes from 20 kΩ to 100 Ω for an applied 95% compressive strain. This material is suitable for a wide variety of sensing applications which include tactile artificial skin for robotics and solvent detection.

Keywords: PDMS; force sensitive resistors; microfabrication; porous scaffold

1. Introduction

A force sensitive resistor (FSR) exhibits a change of resistance in response to an applied physical deformation. FSRs are commonly used for tactile sensing applications where an applied pressure reduces the measured resistance. Piezoresistors, strain gauges, conductive polymers and foams have all been reported as FSRs[1].

Tactile sensing applications can be found in consumer electronics (e.g. computer game controllers) as well as robotics. For example, assistive robotics[2] considers the development of robots for the care of sick and elderly people. It requires sensors which can replicate the behaviour of human skin for gripping objects. The human hand can effortlessly manipulate a brick or a flower whereas a robotic hand needs suitable sensors to provide the same functionality. Elastomeric based FSRs are particularly relevant to this field because they can be used to both sense and grip objects[3].

The Young's modulus of an elastomer, such as Sylgard 184 PDMS, can be lowered by reducing the relative amount of curing agent to base material during mixing. However, this approach is fundamentally limited since the PDMS will not cure with insufficient curing agent. The introduction of an open network of pores into the PDMS leads to a sponge like material which can be readily compressed. In this paper we show that dissolution of a sugar scaffold can be used to form such a porous network and the addition of carbon black creates an FSR. The key motivation behind this work is to develop a cost effective material which shows significant resistance variation in

---

response to a structural deformation. This structural deformation could be a compression, as would be found in a robotic handling application, or an expansion through swelling of the PDMS in a solvent rich atmosphere. PDMS is known to expand due to solvent interaction, the degree to which this occurs depends upon the solvent type, and surface area of the PDMS. The large surface area and continuously porous nature of the conducting sponge presented here is therefore well suited for solvent sensing applications.

2. Fabrication

The sponges are prepared using a manufacturing technique in which a sugar scaffold is used to mould an elastomeric polymer, in this case (poly)dimethylsiloxane (PDMS). A small glass dish was coated with a thin layer of gold using a sputter coater to facilitate the easy removal of cured PDMS. SYLGARD® 184 Silicone Elastomer from Dow Corning was prepared in the glass dish using 10 parts base to one part curing agent by volume. Sugar cubes were placed in the dish, and left for 1 hour to become saturated with PDMS. The cubes were then cured in an oven at 120 °C for 15 minutes, removed and allowed to cool. Excess PDMS was trimmed away, and the cubes put in a beaker of distilled water to dissolve the sugar. Approximately 24 hours were allowed for this process to occur. The water was changed several times during this period to maintain a high concentration gradient between the cube and the water, and thus increase the rate of dissolution.
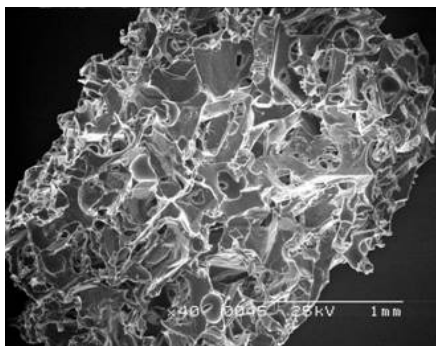

Fig. 1. Electron micrograph of the porous PDMS sponge formed after dissolution of the sacrificial sugar scaffold.

Fig. 1 shows an image of the PDMS sponge created after dissolution of the sugar. The structure is the inverse matrix of a sugar cube, voids are distributed and orientated in a random configuration dictated by the sugar template. Void density is high, resulting in a continuously percolating porous matrix.
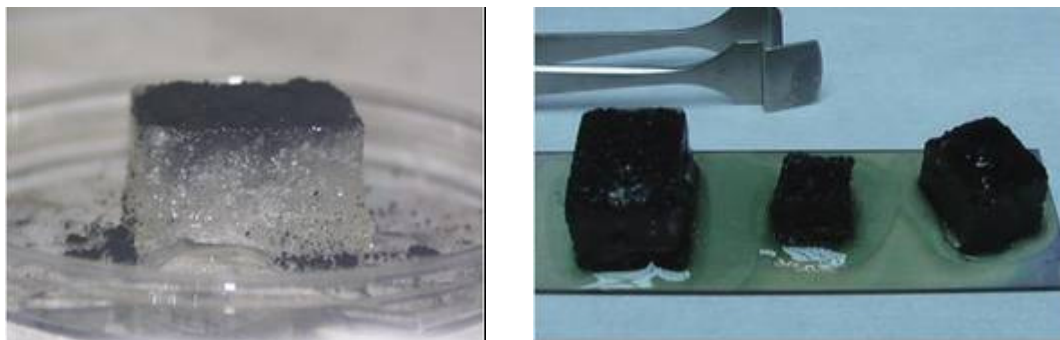

Fig. 2. Photographs of PDMS sponges during (left) and after (right) being filled with carbon black solution.

To introduce the carbon particles to the sponge a suspension of carbon black in water was made, and added dropwise to a water saturated sponge. This proved an effective means of delivery and in Fig. 2 (left) a "front" of

carbon can be seen moving down the sponge. A slow rate of percolation was observed, indicating that a high concentration of carbon is being created within the sponge. Once filled, the sponge was left to dry under ambient conditions then coated with a thin layer of PDMS and cured to seal the carbon inside the sponge. Fig. 2 (right) shows sponges after the percolation of the carbon black.

In the sponge, the pore walls are lined with carbon. In the uncompressed state there is little percolating carbon-carbon contact within the pore, and the pore can be regarded as non-conducting (see Fig. 3). When the pore is compressed, the carbon lined walls come into contact increasing the number of carbon-carbon connections, and the pore becomes conducting. Contact between pores is provided by the narrow inter-pore channels, filled with carbon. These channels are considered to be too small to be greatly affected by the compression of the sponge, they are very small relative to the pores, and are therefore assumed to be constantly conductive by this model. This is validated by the fact that the sponge remains conducting, even for very high strains. The pores are the limiting links in the percolating conductive pathway.
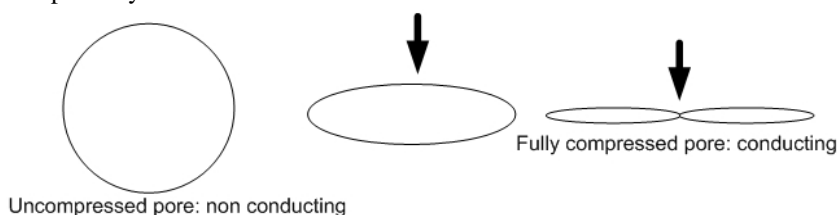

Fig. 3. Compressed pore conduction mechanism through the carbon filled sponge.

3. Experimental Results

A bespoke test rig (Fig. 4) was constructed to give an indication of stress-strain and strain-resistance behaviour over the full compression range of the sponge. The sample is held between two conducting contacts, and compressed by means of a triaxial testing rig (Wykeham Farrance Tritech 50 kN Digital) moving upwards, compressing the sponge against a rigid metal bar. Position of the step (and hence compression) is measured by a Penny and Giles DS131 LVDT, an Oertling OC61 balance records the mass, from which applied force is calculated. Resistance is measured using a multimeter. Displacement and mass were logged using in-house software (Triax version 5.1.5), resistance values were manually recorded. Computer controlled stepwise displacement was not possible using the triaxial testing machine, so displacement steps were applied using manual control.
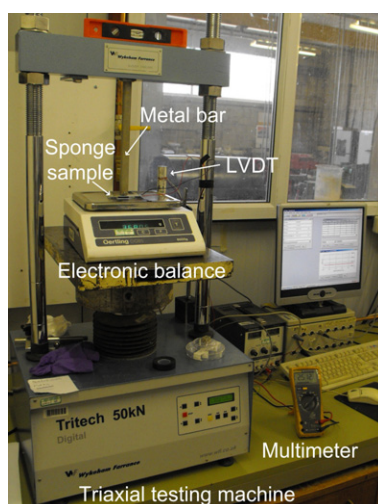

Fig. 4. Photograph of the test rig used to obtain the stress-strain and strain-resistance characteristics.

Fig. 5 shows the measured stress-strain and strain-resistance characteristics for the loading and unloading cycles of a carbon filled PDMS sponge. The gradient of the stress-strain line (i.e. the Young's modulus, E) increases with strain. This corresponds to a Young's modulus of approximately 20 kN/m^2 for up to 30% compressive strain, and for higher strains tends towards the PDMS bulk value of 750 kN/m^2. This is to be expected since the sponge will behave as the bulk under heavy compression due near complete collapse of the pore network.
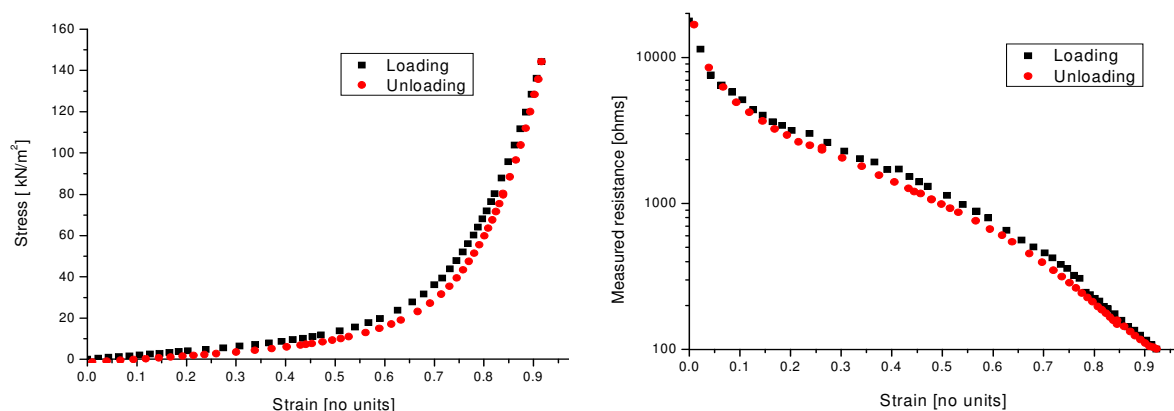

Fig. 5. Measured stress-strain (left) and resistance-strain (right) characteristics across two faces of a carbon filled PDMS sponge in response to applied compressive strain (loading and unloading). The contact area of each face is 247 mm^2 and they are separated, when the sponge is unstrained, by 11.1 mm.

The resistance-strain characteristic is also shown in Fig. 5. In the unstrained state, a large, yet finite resistance is observed. It is clear that a small number of conduction pathways exist within the material, even when no pores are collapsed. As stated earlier, it is proposed that conduction takes place across the carbon lined internal surface of the undeformed pores. The sponge presented here shows a resistance change from 20 kΩ to 100 Ω for an applied 95% compressive strain. This confirms the operation of the carbon filled sponges as force sensitive resistors. Future work will explore the integration of the sponge into tactile and solvent sensors for the applications discussed in the introduction.

In this paper we have demonstrated that a sacrificial sugar scaffold can be used to create a porous PDMS matrix which when filled with carbon black shows a strain sensitive resistance change. This technique produces a highly compressible structure, when compared to bulk PDMS, with a resistance change from 20 kΩ to 100 Ω for an applied 95% compressive strain for the sample presented here.

Acknowledgements

References

1. Fraden J. *Handbook of Modern Sensors, Physics, Designs, and Applications*. 3rd ed, Birkhäuser; 2004

2. Forlizzi J, DiSalvo C, Gemperle F, Assistive Robotics and an Ecology of Elders Living Independently in Their Homes, *Human-Computer Interaction* 2004, **19**, pp 25-59.

3. Sohhawa M, Huang Y-M, Noda M, Kanashima T, Yamashita K, Okuyama M, Ikeda M, Noma H, Fabrication and Characterization of Normal and Shear Stress Sensitivie Tactile Sensors by Using Inclined Micro-Cantilevers covered with elastomer, Proc. MRS 2007; **1052**; 1052-DD04-07