Polyisoprene – nanostructured carbon composite – a soft pressure sensor alternative.

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Latest related research shows natural polyisoprene – nanostructured carbon composite (PNCC) as a promising piezoresistive material for soft pressure sensors. The main advantages of PNCC over conventional sensors are exceptional sensitivity in finger pressure range and possibility to be embedded into soft structures. The current PNCC can be made when certain amount (usually percolative concentration) of high structure electroconductive filler is dispersed into elastomer matrix and vulcanized afterwards.

In this work we specify the percolation threshold for natural polyisoprene rubber filled with Degussa Printex XE2 extra electro-conductive high structure (nanostructured) carbon black, depending on methods of dispersing. After obtaining optimal composition we present a completely soft PNCC pressure sensor prototype, made using multi-gradient approach, when elementary layers with different filler concentration are cured together and forms uniform sensor body with integrated soft electrodes. Afterwards we couple it with simplified analog impulse counter. The prototype system elaborated could be used for counting of interface events between sensor and external environmental factor. If multiple sensor grid approach is used, it could be possible to estimate the distribution and intensity of the external pressure on soft, flat-like surface. These results could be evaluated as a step towards the artificial skin, capable to sense non-destructive interface of the external structure.

POLYISOPRENE – NANOSTRUCTURED CARBON COMPOSITE – A SOFT PRESSURE SENSOR ALTERNATIVE

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The ABSTRACT Latest related research shows natural polyisoprene – nanostructured carbon composite (PNCC) as a promising piezoresistive material for soft pressure sensors [1]. The main advantages of PNCC over conventional sensors are exceptional sensitivity in finger pressure range and possibility to be embedded into soft structures. The current PNCC can be made when certain amount (usually percolative concentration) of high structure electroconductive filler is dispersed into elastomer matrix and vulcanized afterwards [2].

In this work we specify the percolation threshold for natural polyisoprene rubber filled with Degussa Printex XE2 extra electro-conductive high structure (nanostructured) carbon black, depending on methods of dispersing. After obtaining optimal composition we present a completely soft PNCC pressure sensor prototype, made using multi-gradient approach, when elementary layers with different filler concentration are cured together and forms uniform sensor body with integrated soft electrodes. Afterwards we couple it with simplified analog impulse counter. The prototype system elaborated could be used for counting of interface events between sensor and external environmental factor. If multiple sensor grid approach is used, it could be possible to estimate the distribution and intensity of the external pressure on soft, flat-like surface. These results could be evaluated as a step towards the artificial skin, capable to sense non-destructive interface of the external structure.

SAMPLES & EXPERIMENTAL Piezoresistive polyisoprene-nanostructured carbon composite (PNCC) has been previously made by dispersing high structure carbon black (HSCB) and necessary curing agents into polyisoprene matrix using cold rolls (Fig.1). The following raw rubber then can be vulcanized under pressure in hot mould. The disk shaped samples with brass foil electrodes on both sides were prepared from raw rubbers with different carbon content using conventional mixing technique (Fig.2). The percolation threshold was determined (Fig.5). The piezoresistance of preliminary samples (Fig.6,7) of the PNCC was measured using Zwick/Roell Z2.5 universal material testing machine, coupled and synchronized with Agilent A34970A digital multimeter/multiplexer.

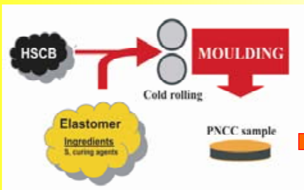

Fig.1 The schematic mixing and preparation diagram of PNCC

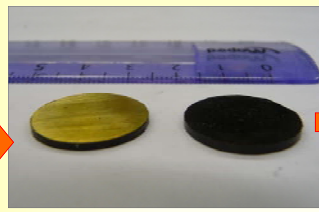

Fig.2 The preliminary test samples with (left side) and without (right side) brass foil electrodes.

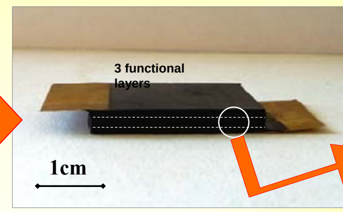

Fig.3 The functional multilayer structure PNCC prototype. The 10 p.h.r. sensitive layer is moulded between two 20 p.h.r. conductive layers with brass foil electrode extensions.

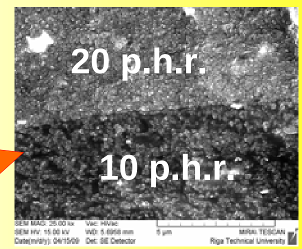

Fig.4 The SEM picture of layer interface.

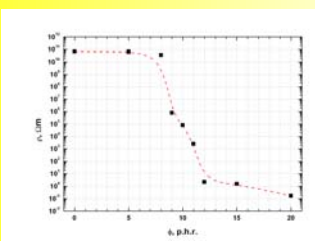

Fig.5 The electrical percolation transition of PNCC.

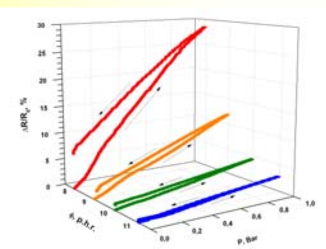

Fig.6 The piezoresistivity of PNCC under operational pressure up to 1 Bar.

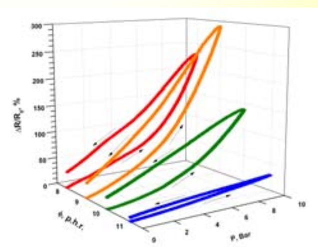

Fig.7 The piezoresistivity of PNCC under operational pressure up to 10 Bar.

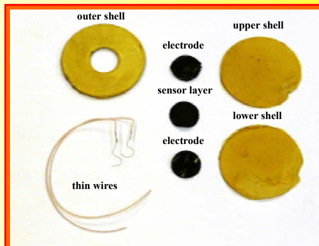

Fig.8 The lay down of an unassembled sensing element prototype.

Fig.9 The functional multilayer complete sensing element prototype. The disk shaped active and conductive layers are moulded into isolative polyisoprene shell.

RESULTS and DISCUSSION The tunneling current existence between closely separated conductor particles are the main conduction mechanism in the vicinity of percolation threshold [1,3,4], where the conductivity of PNCC changes as

$$\sigma \sim |V - V_c|^t, \text{ if } V > V_c, \qquad (1)$$

where: σ – initial specific conductivity, V – concentration of conductive filler, V_c – critical concentration [3].

According to literature, for small strains the resistivity change of PNCC can be explained by tunneling barrier thickness increase [5]. For larger strains the conductive channel rupture becomes active, reducing conductive channel number and increasing the electrical resistivity of PNCC [1]. The observed positive piezoresistivity of PNCC in our case could be explained by transversal slippage causing strain in direction, perpendicular to applied axial pressure, provoking the tunneling barrier thickness increase and sub sequential conductive channel rupture in the direction perpendicular to applied pressure. According to Knite et al. [1] and Chen et al. [6], Luheng et al. [7] proposes the resulting resistivity change as

$$\ln R = \ln R_0 + \ln\left[1+\left(\frac{\Delta L}{L_0}\right)\right] + \sum_{i=1}^{K}\left[A_i \times \left(\frac{\Delta L}{L_0}\right)^i\right], \qquad (2)$$

where: R – resulting electrical resistance of the composite, R_0 – initial electrical resistance, ΔL – deformation of the sample, L_0 – initial thickness of the sample, K is an integral number and A_i (i=1,2,…,K) is coefficient.

Basing on acquired results, the completely soft pressure sensing element design was elaborated, using functional multilayer approach. The completely soft pressure sensing element was made from multiple functional layers of PNCC (Fig.3), each with dedicated concentration of conductive filler. Corresponding layers were pre-formed using incomplete vulcanization in reduced temperature and shorter curing times. Afterwards the layers were cured together using typical vulcanization temperature. The interface between conductive and sensitive layers were checked under SEM for possible de-lamination (Fig.4). To obtain final prototype, necessary pre-vulcanized components were prepared as shown in Fig.8 and cured together until complete vulcanization. Fig.9 shows radial cross-cut of completely soft pressure sensing element, consisting of 3-layer sensitive structure, incorporated into protective isolative rubber shell. The custom made impulse counter interface was elaborated and connected to sensing element (Fig.10) to promote its possible practical application.

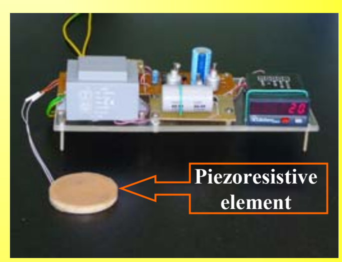

Fig.10 The final prototype of completely soft pressure sensor attached to custom-made impulse counter interface.

CONCLUSIONS

→The piezoresistive behavior of PNCC samples can be expressed using two process approach – taking into account the change of tunneling currents for smaller deformations, as well as the rupture of conductive paths caused by transversal slippage of elastomer under large axial strains.
→The PNCC proved itself as a good pressure sensitive material for sub-Bar, as well multi-Bar pressures.
→The completely soft pressure sensing element has been elaborated and tested, using functional multilayer approach.

AKNOWLEGMENTS

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