POLYISOPRENE-NANOSTRUCTURED CARBON BLACK AND CARBON NANOTUBE COMPOSITES AS PROGRESSIVE TENSILE AND COMPRESSIVE STRAIN SENSING MATERIALS

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Topical division: N (nanostructured materials)

The change of electrical resistivity depending on mechanical loading applied (the tensoresistive and piezorezistive effect) in polyisoprene-nanostructured carbon nanoparticle composites (nanocomposites) is experimentally studied. Dependence of the electrical resistance on time, strain and stress is examined. High structure carbon nanoparticles (mean diameter 30 nm, dibuthyl phthalate adsorption 380ml/100g, specific surface 950 m^2/g) and multi-wall carbon nanotubes (MWCNT) have been used as the filler. Solvent based mixing technology before curing for sample preparation is used. Finally the mechano-electric properties of different composites are compared and functional models of both piezo and tenzoresistive effect are proposed and practical usage fields are discussed as well. Conclusions are made, that multi wall carbon nanotube composites can be used as strain sensing elements at smaller strain ranges comparing with carbon black filled ones. On other hand they have certain resistivity "memory effect" during large (more than few %) strain deformations.

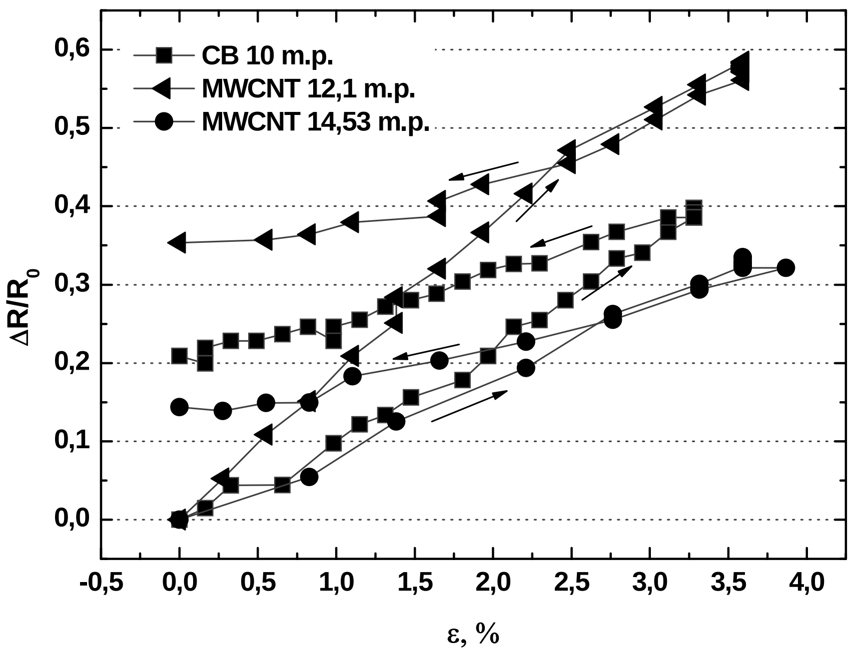

Fig. 1 Relative change of electrical resistivity as function of strain for polyisoprene-nanostructured carbon black composites, depending on filler used.

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Introduction. Broad use of compressive and strain sensors requires new materials to be designed for particular application. Recent research approved nanostructured carbon-elastomer composite to be a perspective material for current needs [1,2]. At certain concentrations of conductive filler it showed remarkable reversible tenso and piezorezistive effect [3,4]. Use of such composites could lead to mass production of cheap, variable size completely flexible sensors with wide rage of application. But there are still many questions about mechanism that drives this phenomena. Electrical resistance vs both tensile strain and stress (the tensoresistive effect) in polyisoprene-nanostructured carbon nanoparticle composites (nanocomposites) is experimentally studied in this work. The character of mechano-electric relaxation of the composites is examined and relaxation models proposed. Finally the possible use of elastomer – nanostructured carbon black composites as deformation sensors are discussed.

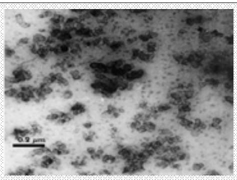

Fig.1. Continuous electro conductive network, formed by dispersed ECB particles in the elastomer matrix [5].

The stand of the problem. At concentrations close to percolation threshold the filler tries to form a continuous conducting network (Fig.1) [5]. In our case it's been proven that tunneling currents between closely separated particles play a major role in the mechanism of conductivity. The change of conductivity is connected with both – the breakdown and recombination of electro conductive network paths and the change of intensity of the tunneling currents [6]. The question is: ***What kind of material could be better used for this aplication (higly structured carbon black or multi wall carbon nanotubes)?*** To get an answer we must have a look on basic tensoresistive properties of both composites. Therefore we must compare the relative tensoresistive effect, relaxation cinetics and initial specific resistivity of composites.

ECB PRINTEX XE2	
Specific surface area, m^2/g	950
DBT absorbtion rate, ml/100g	380
Ash content, %	1
Average particle size, nm	~30

Table 1. Main characteristics of ECB used.

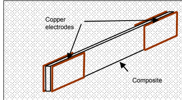

Fig. 2. Structure of sample.

Samples and experimental procedure. Thick Pale-Crepe natural polyisoprene was used as isolative matrix. Degussa™ Printex™ EX-2 high structure electro-conductive carbon black (ECB) and multi wall carbon nanotubes (MWCNT) were used as a conductive filler. The main characteristics of ECB are shown in Table 1. Electro-conductive filler was mixed into matrix using solven mixing techology and resulting material was dried and afterwards cured under high pressure at 160ºC for 20 minutes. Resulting material was formed into sheets with thickness of 1 and 3 mm. Samples were cut out from these sheets and copper foil electrodes were glued at the end of the samples, as shown in the Fig. 2. The universal paper testing machine was used for stretch tests. Applied force, elongation and electrical resistivity were measured at the same time using digital Vernier™ LabPro™ laboratory data acquisition hardware and software. Relative elongation, strain and specific resistivity were calculated out from results collected.

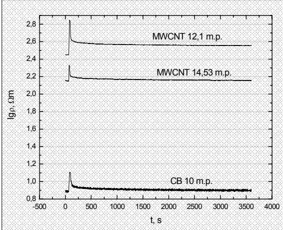

Fig.3. Specific resistivity of polyisoprene – nanostructured carbon composites as a function of time during and after release of 3.33% strain; m.p. - mass part of filler per 100 parts of polyisoprene.

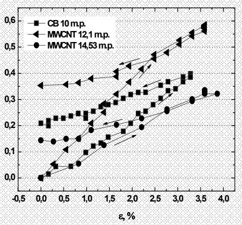

Fig. 4. Relative change of electrical resistivity as a function of strain for polyisoprene-nanostructured carbon black composites, depending on filler used.

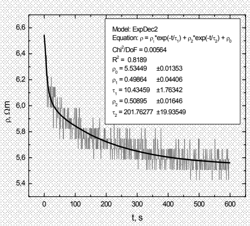

Fig.5. Specific resistivity during relaxation as a function of time for PI with 10 mass parts of ECB. Fitted using 2 component exponential decrease.

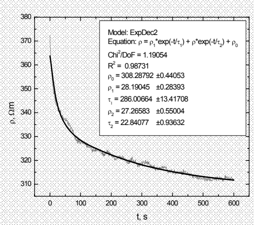

Fig.6. Specific resistivity during relaxation as a function of time for PI with 12,1 mass parts of MWCNT. Fitted using 2 component exponential decrease.

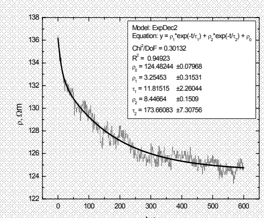

Fig.7. Specific resistivity during relaxation as a function of time for PI with 14,53 mass parts of MWCNT. Fitted using 2 component exponential decrease.

Results and discussion.

Samples with 10 mass part ECB, 12,1 and 14,53 mass part MWCNT were exposed to stretch at 3,3 % relative elongation, kept stretched for 10 seconds and then released to 0% elongation. During this process and 10 minutes afterwards the electro-mechanical parameters of samples were measured. The time dependance of of specific electrical resistivity were recorded after release of strain. Results collected were plotted using Origin™ v7.5 data analyse software (Fig.3, 4). First the relative changes of resistivity of both type materials were compared. It was noted, that composite containing 12,1 mass part of MWCNT showed better tensoresistive effect than composite with 10 mass parts CB during similar stretching conditions. In the same time we can clearly see that the same composite showed remarkably larger remaining initial resistivity excess after complete release of strain (Fig.4). To find a explanation it is necessary to take a close look at mechano-electrical relaxation properties. As it is known most releaxation processes are well expressed by one component exponential decrease equations: $\rho = \rho_0 + \rho_1 exp(-t/\tau)$. One component exponential showed noticeable leak of accuracy by fitting our data. Two component exponential: $\rho = \rho_0 + \rho_1 exp(-t/\tau_1) + \rho_2 exp(-t/\tau_2)$, seems to be acceptable (Fig.5, 6 and 7). This shows, that there are at least two processes with different relaxation kinetics involved in the change of structure of composite material leading to change of conductivity in relaxed state. Coexiastance of many relaxation processes could be the reason leading to intensive and long lasting relaxation of electrical properties of the composite. We can conclude that movement of MWCNT during the end of stress and strain relaxation in material is more difficult than movement of ECB particles. This leads to lower rate of recombination of the initial conductive network after release of strain.

Conclusions.

→ Solvent mixing technology for making poliisoprene-nanostructured carbon black composites have been acquired.

→Poliisoprene-nanostructured carbon black composite filled with MWCNT an ECB both can be used as strain sensing materials.

→ Composites, filled with 12,1 mass parts MWCNT shows greater response to small applied strain (3,3%) comparing with ECB filled ones.

→ Composites, filled with MWCNT have large remaining excess of initial resistivity after complete releaase of strain.

References:

1. L.Flandin, Y.Brechet, J.-Y.Cavaille. Electrically conductive polymer nanocomposites as deformation sensors. *Compos. Sci. Technol.,* 2001, 61, p. 895-901.
2. A.E.Job, F.A.Oliveira, N.Alves, J.A.Giacometti, L.H.C.Mattoso. Conductive composites of natural rubber and carbon black for pressure sensors. Synthetic Met. (135-136), 2003, p. 99-100.
3. M.H.Ali, A.Abo-Hashem. Percolation concept and the electrical conductivity of carbon black-polymer composites. 3: Crystallisable chloroprene rubber mixed with FEF carbon black. *J. Mater. Proc. Tech.,* 1997, 68, p. 168-171.
4. M.Knite, V.Teteris, A.Ķiploka, J.Kaupuzs. Polyisoprene-carbon black nanocomposites as tensile strain and pressure sensor materials. *Sensor. Actuator.,* 2004**,** 110, p. 142-149.
5. J.S.Bergström, M.C.Boyce. Large strain time-dependent behavior of filled elastomers. *Mech. Mater.,* 2000**,** 32, p. 627-644.
6. M.Knite, V.Teteris, B.Polyakov, D.Erts. Electric and elastic properties of conductive polymeric nanocomposites on macro- and nanoscales. Mater. Sci. Eng. C. 2002, 19, p. 15-19.