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The influence of hydrostatic pressure and transverse magnetic field on the electric conductivity of the magnetorheological elastomers

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ABSTRACT

Two sets, each of five samples, of magnetorheological elastomers (MREs) based on silicone rubber and carbonyl iron were prepared. One set of samples was obtained by polymerization of the silicone rubber with additives in the absence of the magnetic field, while the other by polymerization of the silicone rubber with additives in the presence of the magnetic field (840 kA/m). The samples from each set differ by volume concentration of the magnetic phase. By means of an experimental setup described in the paper, the electrical resistance R of the samples was measured as a function of the force F applied on the surface of the samples, for fixed values of the transverse magnetic field strength H. From the as-measured dependence $R = R(F)_H$, the dependence $\sigma = \sigma(p)_H$ of the electric conductivity σ on the applied pressure p was determined. The experimental results are discussed in view of possible applications like magneto-mechanical sensors working in hostile media.

1. Introduction

Magnetorheological elastomers (MREs) are part of a category of materials called "magnetically active" [1]. They contain an elastic matrix (e.g. rubber and silicone rubber) in which magnetic nano- and/or microparticles are either dispersed or ordered [1–10]. Like the magnetorheological suspensions [11–14], the rheological properties of the MREs change reversibly with the application and cancellation of an external magnetic field.

This property makes possible the use of MREs to the manufacture of smart devices as vibration dampers and mechanical shock [15–18]. Recently, it was shown in Refs. [4–8,19] that during the application of a magnetic field, electric micro-contacts are produced between the conducting particles from MREs. The density and the strength of these electrical microcontacts both depend on the intensity of the applied field, on the magnetic properties of the magnetizable phase and on nature of the elastic matrix. It was shown in Refs. [4–8,19] that the electroconductivity of the MREs in a magnetic field can be used for manufacturing of magnetoresistors, Hall probes and magnetically controllable electric capacitors. In order to enlarge the knowledge area regarding the MREs' electro-conductivity in a magnetic field, the effect of the hydrostatic pressure, of the volume concentration of the magnetizable phase and the influence of the transverse magnetic field are examined in the present paper. The obtained results may be of interest for the manufacturing of voltage sensors and static and dynamic mechanical deformation transducers.

2. Production of the MRE samples

2.1. Procedure

According to the installation configuration (Section 3), the MRE samples are disc-shaped, 6 mm thick and 25 mm in diameter. Two samples of the same composition are produced: one by polymerization in a magnetic field, the other one in the absence of the field.

The necessary materials for the production of the samples are:

- silicone rubber (SR) type RTV-3325 (Bluestar-Silicones),
- catalyst (C) type 60R (Rhône – Poulenc),
- carbonyl iron (CI) with granularity between 4.5 μm and 5.4 μm, iron content min. 97% (Merck), and
- silicone oil (SO) with viscosity of 250 mPa s at 298 K (Merck).

Two sets are produced, each with five samples. The volumes of materials used for every sample are given in Table 1. Samples obtained by polymerization of SR with additives in magnetic field are denoted with S_{mi} (where $i = 1, 2, \ldots, 5$), and samples obtained by polymerization of SR with additives in the absence of the magnetic field are denoted with S_{oi} (where $i = 1, 2, \ldots, 5$).

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Table 1
Materials for the MRE samples.

Sample type	Materials	Volume/sample $10^8 \times V$ (m^3)	α (%)
	SR	4.8	30
S_{01}	CI	2.4	
S_{m1}	SO	0.4	
	C	0.4	
	SR	4.0	40
S_{02}	CI	3.2	
S_{m2}	SO	0.4	
	C	0.4	
	SR	3.6	45
S_{03}	CI	3.6	
S_{m3}	SO	0.4	
	C	0.4	
	SR	3.2	50
S_{04}	CI	4.0	
S_{m4}	SO	0.4	
	C	0.4	
	SR	2.4	60
S_{05}	CI	4.8	
S_{m5}	SO	0.4	
	C	0.4	

Note: α is the volume concentration of the magnetic phase from inside the elastic matrix; S_{oi}/S_{mi} ($i = 1, 2, \ldots, 5$) are samples polymerized in the absence of the magnetic field/in the presence of the field.

For the production of the samples, one proceeds as follows: CI and SO, in the amounts given in Table 1 for each sample, are mixed and heated for approx. 5 min to the temperature of 573 K $\pm$ 10%. The as-resulting mixture is then homogenized during slowly cooling down to 373 K $\pm$ 20%. At this temperature, the mixture is completed with SR and C, in volumes according to Table 1.

The as-obtained product is poured into matrixes. The matrix used for the S_{mi} samples is introduced between the poles of a Weiss electromagnet. The intensity of the magnetic field is fixed to $H = 840$ kA/m $\pm$ 10%, and the sample is maintained in the field for 6 h. The polymerization temperature is 284 K $\pm$ 10%, and the duration of the complete process is 24 h. The samples extracted from the matrixes are left in the environment for about 72 h, in order to remove the traces.

2.2. The magnetoresistor

The magnetoresistor (MR) is an assembly formed from two non-magnetic electrodes which make electric contact with the MRE [7,8,19]. Copper electrodes with a diameter of 25 mm and 0.35 mm thickness are used, by gluing on the surfaces of the MRE discs with a mixture of poxipol and 55 vol% graphite microparticles having approx. 45 μm granularity. In a magnetic field $H = 200$ kA/m, the electric resistance of the as-formed contact between the electrodes and the MRE surface is negligibly small compared to that of the bulk.

3. Experimental installation

The experimental installation used for the study of the electric conductivity of the S_{oi} and S_{mi} (where $i = 1, 2, \ldots, 5$) samples is presented in Fig. 1. It contains a DC electromagnet, having a magnetoresistor between the poles. The MR's electrodes are connected to the ohmmeter Ω (Fluke 884GA type or UT70A multimeter). On the free surface of the MR, a pressure p will appear, by applying the F force. The force is transmitted to the sample by means of a piston made from a non-magnetic rod, having at the bottom end a 4 mm thick disc of 25 mm diameter.

The intensity H of the magnetic field is measured in the absence of the sample with the gaussmeter GM-04. The values of R were measured after 15 s from the application of H.

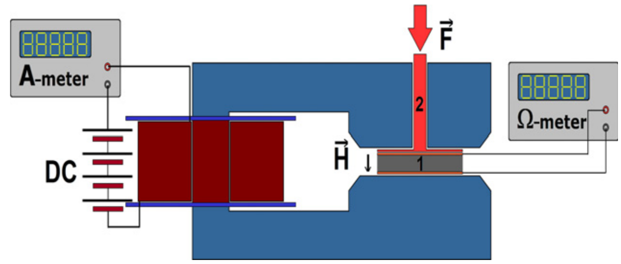

Fig. 1. Experimental installation (ensemble configuration): A, amperemeter; DC, power-supply, LAB EC 3010 type; $\vec{F}$, force; $\vec{H}$, magnetic field intensity vector; Ω, UT70A multimeter or Fluke precision multimeter 8846G type; 1, magnetoresistor; 2, copper rod with copper disc.

4. Results and discussion

R measurements were carried out for field values $H = 100$ kA/m and $H = 200$ kA/m and applied forces between 10 N and 110 N. For the MRs with samples S_{o1} and S_{m1}, no electric conductance ($R \to \infty$) was detected. Conversely, a dependence $R = R(F)_H$ was clearly observed for all the other S_{oi} and S_{mi} ($i = 2, 3, 4, 5$) as shown in Fig. 2 ($H = 100$ kA/m) and Fig. 3 ($H = 200$ kA/m). It can be noticed from Figs. 2 and 3 that for fixed F and H, the R values slightly differ as the samples were obtained by polymerization in the absence or in the presence of the field. For both sets of samples R decreases as F

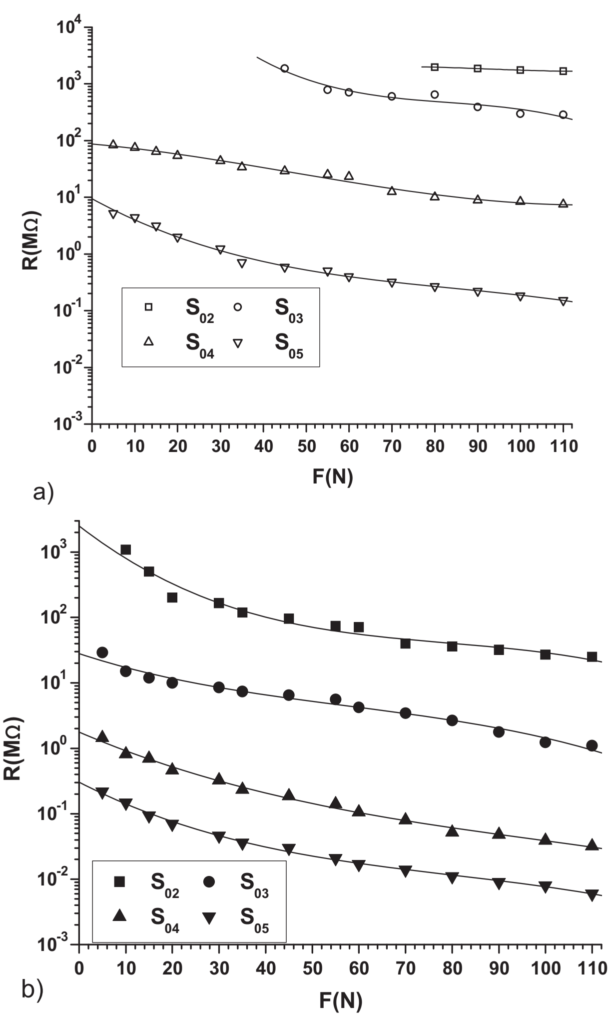

Fig. 2. R versus F, for $H = 100$ kA/m, for: (a) the MRs with samples S_{oi} ($i = 2, 3, 4, 5$); (b) the MRs with samples S_{mi} ($i = 2, 3, 4, 5$), continuous lines – fit data.