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Magnetodielectric effects in hybrid magnetorheological suspensions

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ABSTRACT

The magnetodielectric material obtained is a hybrid magnetorheological suspension (MRS-hybrid) which contains polyurethane sponge foam, magnetorheological suspensions (MRS) and polymerized silicone rubber. We create a plane capacitor based on MRS-hybrid. Using a programmable bridge we measure the capacitance C and the dissipation factor D of the capacitor as a function of intensity H of a constant magnetic field, and as a function of frequency f of an electric field. We determine the components ϵ' (relative dielectric permittivity) and ϵ'' (dielectric loss factor) of the complex dielectric permittivity ϵ^* of MRS-hybrid. We present and discuss the obtained results.

Introduction

Materials whose physical properties are influenced by changes of *pH*, intensity of an applied electric or magnetic field have the generic name of "smart materials". This type of materials has found important applications in electronics [1], vibrations control [2] and bio-medical research [3]. One of the most representative classes of smart materials are magnetorheological suspensions (MRSs), electrorheological fluids (ERFs) and magnetorheological elastomers (MREs). MRSs are biphasic fluids which contains a fine powder (*Fe*, *Ni*, *Co* microparticles or their alloys) of a magnetizable phase dispersed in a liquid matrix (mineral/silicone oils). Under an applied magnetic field, the microparticles become magnetized and form chains aligned along the magnetic field lines. The strength of the chains depends on the type of particles and on the magnetic field intensity [4,5].

Formation of chains of microparticles in the liquid matrix determines a modification of the physical characteristics of MRSs in general, and of rheological properties [1–7] in particular. The latter property of MRSs is used for development of vibration dampers and mechanical shock attenuators or for production of clutches with a coefficient of mechanical coupling (coefficient which depends on the volume of magnetizable phase) controlled by the intensity of an applied magnetic field [8]. Recently, it has been shown that under the influence of a magnetic field, MRSs have electroconductive properties [9–14]. Microparticles having a diameter between 1 and 10 μ m settle in the liquid matrix, and solving this issue (partially or totally) is achieved by introducing additives such as carbon nanotubes [15] or of graphene nanoparticles [16]. In both cases one obtains an improved stability and better physical characteristics of MRSs with additives.

For ERFs systems, the liquid phase consists of dielectric microparticles (silica, aluminosilicate and cellulose) dispersed in a liquid matrix based on mineral/silicone oils, etc. Immediately after application of an electric field, the microparticles become electrically polarized. In the liquid matrix are formed chains of electric dipoles, which leads to important modifications of rheological properties of ERFs [17–20]. This property is largely used in damper systems [21], tactile display [22] and torque elements used in rehabilitation devices [23].

In the case of MREs, the matrix is an elastic solid (natural/silicone rubber, etc.) and the magnetizable microparticles are fixed

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to the polymer chains. In magnetic field, the elastic properties and viscosity are drastically changed [24–26] and therefore MREs can be used for manufacturing magnetic field sensors or mechanical tension sensors [27,28].

Electrical properties of MRSs [9–14], MREs [24–28] and of ERFs [21,29] indicate that the dielectric function of these materials, for a given composition, is influenced by the frequency of the electric field or by the intensity of the magnetic field. In this paper we fabricate a MRS-hybrid based on polyurethane sponge foam (PSF), magnetorheological suspensions (MRS) and polymerized silicone rubber, and investigate its dielectric function in magnetic field, for fixed values of the frequency of an electric field. The obtained results can be important for various applications, such as in fabrication of mechanical shock attenuators in civil and industrial constructions, or in orthopedics.

Experiment

Production of MRSs

Materials used for fabrication of MRSs are:

- carbonyl iron (CI) powder, from Merck, containing microparticles with average sizes ranging from 4.5 to 5.4 μ m and with an iron content of min. 97%;
- silicone oil (SO), from Merck, with viscosity $\eta = 0.2$ Pa s (at $T_0 = 293$ K) and ignition temperature $T_i = 733$ K [30].

One prepares a mixture of SO (30×10^{-6} m^3 vol.) and CI (20×10^{-6} m^3 vol.). During homogenization the mixture is brought to $T \approx 600$ K and is kept at this temperature for about 900 s. During the thermal treatment the humidity from CI is removed. At room temperature one obtains an MRS stable for about 12 h [31]. The magnetic behavior of the MRS sample is examined in 50 Hz fields, by means of an integrating fluxmeter [32]. The magnetization curve obtained with this method is shown in Fig. 1 where we can see that the response of MRS is superparamagnetic [33], and is similar to that of magnetic fluids. The saturation magnetization of MRS is $M_s = 0.344$ kA/m.

Capacitors

Materials used for fabrication of capacitors are:

- polyurethane sponge foam, produced by Euroform, having the structure shown in Fig. 2;

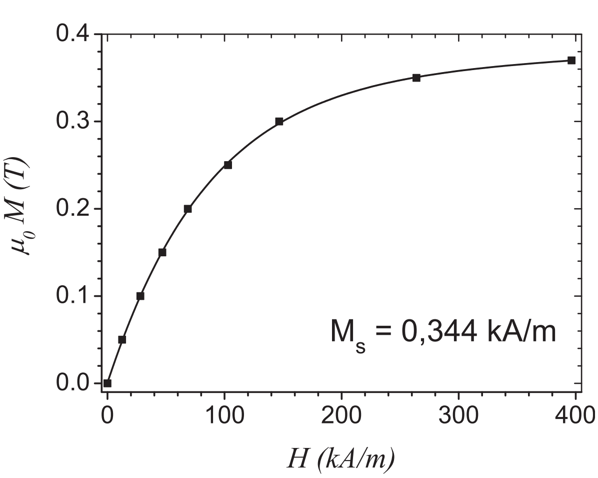

Fig. 1. Magnetization curve of MRS.

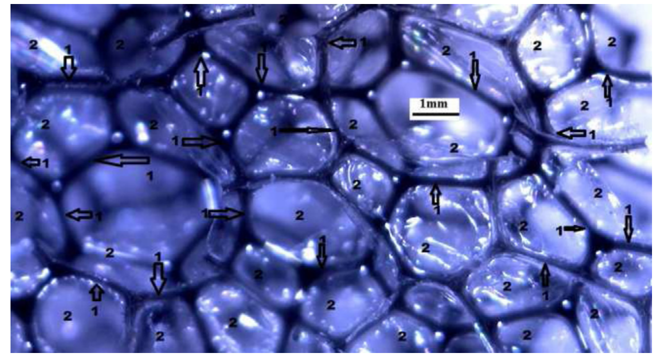

Fig. 2. PSF foil image obtained using the digital microscope TASCO 120: 1, cell's wall; 2, cell.

- crystalline graphite powder (CGP) produced by Chatengpur Graphite Industries with maximum sizes of 53 μ m;
- liquid adhesive (LA) based on cyanoacrylate, produced by Poxipol;
- copper bands (CB), 3*M* – 1245 – 19 type, produced by 3 M;
- silicone rubber (SR), *RTV*3325 type, produced by Bluestar-Silicone;
- catalyst (C), 60 *R* type, produced by Rhone-Poulenc.

The fabrication process of the capacitor is the following: first, one cuts a piece with dimensions 0.92 m × 0.92 m × 0.02 m from the PSF plate. Then, on each parallel sides of dimensions 0.92 m × 0.92 m one fixes by gluing, copper electrodes. Each electrode has dimensions 0.03 m × 0.03 m × 0.0015 m ± 5% and they are fixed at a distance 0.020 m ± 0.0015 m from each other, using an adhesive solution consisting of CGP (~ 70 vol.%) and LA (~ 30 vol.%). The obtained ensemble is introduced in MRS for ~ 24 h. During this time, the MRS absorbed in PSB is ~ 70 vol.%. The as-obtained composition is introduced into a mold of dimensions 0.070 m × 0.060 m × 0.040 m and fixed at half distance from the mold's walls. Finally, a liquid solution consisting of SR (95% vol.) and C (5% vol.) is poured into the mold, until it is completely filled. After polymerization of the final mixture, one obtains a capacitor with dielectric material based on MRS-hybrid.

Experimental setup

The experimental setup used for studying the magnetodielectric effects in the obtained dielectric material is described in Fig. 3. It consists of a Weiss electromagnet (Phylotex type) composed of the magnetic yoke and coils connected to a source of direct current S, the capacitor connected to the bridge P and a Hall probe connected to the Gaussmeter G.

The intensity $\vec{H}$ of the magnetic field is measured at half the distance between the magnetic poles, using the Hall probe

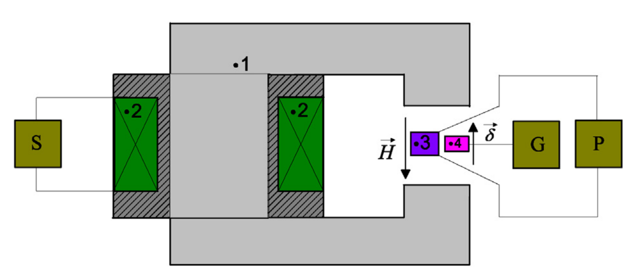

Fig. 3. Experimental setup (ensemble configuration): S, DC power supply (Lab Ec – 3010 type); G, Gaussmeter *GM* – 04 type; P, programmable LCR bridge *HM* – 8118 type; 1, magnetic yoke; 2, coil; 3, capacitor; $\vec{H}$, magnetic field intensity; $\vec{\delta}$, gradient of magnetic field intensity; 4, Hall probe *T*4002 type.