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Influence of magnetic field on dispersion and dissipation of electric field of low and medium frequencies in hybrid magnetorheological suspensions

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ABSTRACT

We have obtained hybrid magnetorheological suspensions (MRS-hybrid) consisting of magnetorheological suspension (MRS), magnetorheological elastomer (MRE) and polyurethane sponge foam (PSF). We measure the capacitance and resistance of a plane capacitor based on MRS-hybrid, as a function of frequency f of an electric field superimposed with a magnetic field of intensity H. The relative dielectric permittivity ϵ', dielectric loss factor ϵ'' and electrical conductivity σ are significantly changed when $0.02 \leq f(\text{kHz}) \leq 200$ at $H = 0$, 100, 200 and 400 kA/m. The static and optical dielectric constants are greatly influenced by the magnetic field intensity. We present and discuss the results using the model of dipolar approximation.

1. Introduction

Magnetorheological materials (MRs) are a class of smart materials whose mechanical, electrical and magnetic properties can be strongly influenced by application of a magnetic field. One of the most representative classes of MRs are magnetorheological suspensions (MRSs), magnetorheological elastomers (MREs) and magnetorheological gels (MRGs) [1].

The yield stress and apparent viscosity in MRSs are strongly influenced by the presence of a magnetic field [2] and therefore this property is largely used for production of various devices such as dumpers and clutches [3,4]. Under the influence of a magnetic field the distances between magnetic dipoles of MRS are changed, and between electrically conducting particles arise resistances of contact. The effect of electrical resistance of contact is to modify the electrical conductivity while the effect of thermal resistances of contact is to modify the thermal conductibility [5–8].

MREs are a new class of MRs in which the modulus of elasticity is rapidly changed after application of a magnetic field [9], property extensively used in various applications such as adaptive retuned vibrations absorbers [10], stiffness-tunable mounts and suspensions [11], or variable-impedance surface [12,13]. Changes in moduli of elasticity are highly connected with changes in electrical conductivity of MREs in magnetic field as well as with changes in compression pressures [14–18].

Due to these physical properties, fabrication of advanced materials based on MR (i.e. MRSs, MREs, MRGs etc.) has become an active research area in the last years. For example, in ref. [1] it is fabricated a composite MRE-hybrid consisting of MRE (the base matrix) and MRSs or MRGs columns, and it was found that the values of storage and loss moduli are noticeably higher than those corresponding to MRE, for the same values of magnetic field intensity. By using a resistor body based on graphene nanoparticles, in ref. [14] is fabricated a MRE-hybrid where the electrical conductivity is substantially influenced by small values of the magnetic field intensity, and respectively by small values of mechanical compression stress. In addition, electrical conductivities of MRE-hybrid are constant with time [14], which is in contrast with the electrical conductivities corresponding to MRE-based devices [17] and which are characterized by non constant values with time.

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The size of MR-effect in MRSs is very important since it is desirable to have a distinguishable response at small values of excitations (magnetic field, stress and strain fields, viruses, bacteria etc.). Therefore, the aim of this paper is to show the fabrication process of a MRS-hybrid and to describe the MR-effect under the application of an electric field of low and medium frequency superimposed with a magnetic field.

2. Material and methods

Materials used for fabrication of MRS-hybrid are:

- carbonyl iron (CI) powder, from Merck, containing microparticles with average sizes ranging from 4.5 μm to 5.4 μm and with an iron content of min. 97%;
- silicone oil (SO), from Merck, with ignition temperature $T_i = 733$ K [19];
- polyurethane sponge foam (PSF), from Euroform;
- silicone rubber (SR), RTV 3325 type, from Bluestar-Silicone;
- catalyst (C), 60 R type, from Rhone-Poulenc;
- copper bands, 3M-1245-19 type, from 3M;

MRS is obtained by mixing CI powder (40 vol.%) with SO (60 vol.%) at ~600 K for about 900 s, followed by cooling down of the mixture to room temperature (~300 K). A PSF plate with dimensions $0.050 \times 0.040 \times 0.020$ m^3 is immersed in MRS. On each side of the plate we add copper electrodes with dimensions $0.030 \times 0.030 \times 0.0015$ m^3. After ~24 h, PSF containing ~70 vol.% MRS, is introduced into a mold with dimensions $0.060 \times 0.070 \times 0.040$ m^3. MRS wets the polyurethane foam and during immersion the contact surface tension between MRS and the walls of capillary cells is big. This solid–liquid interface tension generates a surface force which drives MRS inside the capillaries of the body sponge. A solution containing 65% SR, 10 vol.% CI and 5 vol.% C is poured into the mold. After ~24 h one obtains an elastic body which will be called MRS-hybrid. Fig. 1 shows a plane capacitor having the MRS-hybrid as dielectric.

3. Results and discussions

The plane capacitor shown in Fig. 1 is connected to a programmable Hameg RLC bridge, $NM - 8118$ type. Between the poles of the electromagnet the magnetic field is not homogeneous and along the thickness of the capacitor is established a gradient $\vec{\delta}$(kA/m^2) of the magnetic field intensity. The intensity $\vec{H}$ of the magnetic field is measured at half of the capacitor's thickness. The variation of δ (kA/m^2) with H is shown in Fig. 2. In the absence and, respectively in the presence of a constant magnetic field of gradient δ (kA/m^2) one measures the equivalent capacitance C and equivalent resistance R as a function of the frequency f of the applied electric field. The obtained values are shown in Fig. 3 and, respectively in Fig. 4 where we can observe that the values for C and R are changed with increasing frequency f of the electric field and they are influenced by the magnetic field.

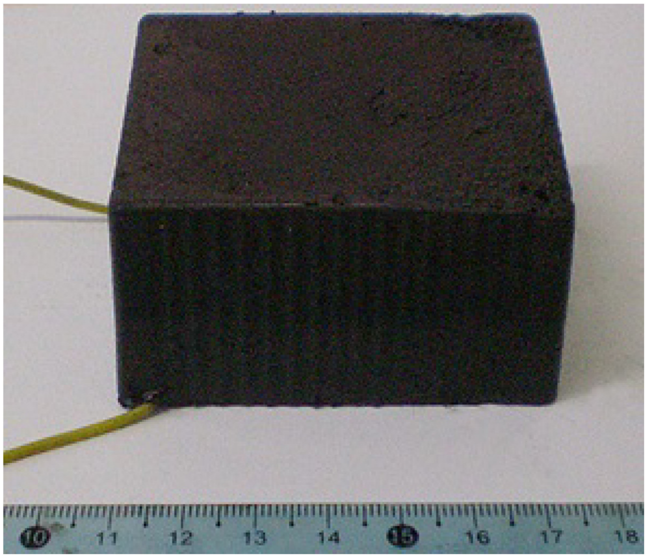

Fig. 1. A plane capacitor having MRS-hybrid as dielectric. Electrically this is equivalent with two plane capacitors connected in parallel: one containing PSF with MRS as dielectric, and second one containing MRE as dielectric.

In the absence of magnetic field ($\delta = 0$ (kA/m^2)) the capacitance $C = 63.997$ pF at $f = 20$ Hz decreases with increasing the gradient of magnetic field. At $f = 120$ kHz one obtains $C_{\min} = 23.126$ pF followed by an increase up to $C = 30.165$ pF at $f = 200$ kHz. By applying a magnetic field the shape of the curves $C = C(f)_H$ is changed. Therefore, for $H = 100$ kA/m at $f = 20$ Hz one obtains $C = 1239$ pF. With further increase of f the capacitance C of the plane capacitor decreases. At $f = 120$ kHz one obtains $C_{\min} = 32.3$ pF. For $f > 120$ kHz, C increases with increasing f and at $f = 200$ kHz one obtains $C = 34.833$ pF. On another hand, by increasing the values of H one obtains: $C = 1746$ pF at $f = 20$ Hz and $C = 38.18$ pF at $f = 200$ kHz for $H = 200$ kA/m, and respectively $C = 2003$ pF at $f = 20$ Hz and $C = 53.59$ pF at $f = 200$ kHz for $H = 400$ kA/m.

The equivalent resistance R of the plane capacitor decreases with increasing the frequency f of the electric field and it is influenced by the value of the magnetic field intensity H. Therefore at:

- $H = 0$ one obtains $R = 938$ MΩ at $f = 20$ Hz, and $R = 41.68$ kΩ at $f = 200$ kHz;
- $H = 100$ kA/m one obtains $R = 1.4288$ MΩ at $f = 20$ Hz, and $R = 19.35$ kΩ at $f = 200$ kHz;
- $H = 200$ kA/m one obtains $R = 193$ kΩ at $f = 20$ Hz, and $R = 167$ kΩ at $f = 200$ kHz;
- $H = 400$ kA/m one obtains $R = 100$ kΩ at $f = 20$ Hz, and $R = 10.8$ kΩ at $f = 200$ kHz.

In a magnetic field with a gradient δ (kA/m^2), CI microparticles become magnetic dipoles which in turn give rise to magnetic interactions (Fig. 2). Then, the intensity of magnetic interaction between two neighboring magnetic dipoles can be written as [20]

$$F'_{\mathrm{mag}} = -\frac{\pi}{6}\mu_0 a^3 M \delta, \quad (1)$$

where μ_0 is the magnetic permeability of vacuum, a is the average radius of the magnetic dipole and M is magnetization. Under the influence of the force F'_{mag}, in the viscoelastic matrix arise the reaction force

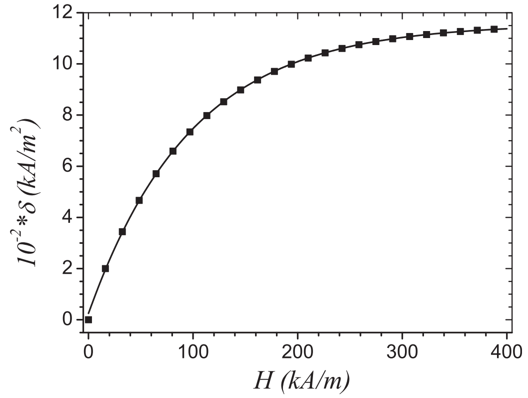

Fig. 2. Gradient δ (kA/m^2) vs. the intensity H of the applied magnetic field.