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Magnetic flux density effect on electrical properties and visco-elastic state of magnetoactive tissues

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ABSTRACT

Magnetoactive tissues are prepared from a mixture of silicone oil (SO) and various volume concentrations Φ of carbonyl iron (CI) microparticles impregnated in a cotton cloth. The obtained tissues are examined as dielectric materials for manufacturing electrical capacitors. By using the plane capacitor method, we show that the relative dielectric permittivity, apparent viscosity, modulus of elasticity, and the components of deformations and of mechanical tensions can be sensibly influenced by an external magnetic field and by Φ. These effects make the obtained tissues versatile candidates for applications which require textiles consisting of conductive fillers, powders, yarns etc. embedded into non-conductive fabric fibers and with pre-established strength and flexibility. An immediate application is in fabrication of magnetic field sensors for detection of magnetic flux densities in the range 40 ÷ 180 mT.

1. Introduction

More and more sophisticated needs of contemporary society call for unprecedented scientific, technological and informational progress. Satisfying these needs requires the use of technologies, equipment and devices that generate chemical, acoustic and more recently electromagnetic pollution [1,2].

Electrotechnical and electronic equipment for industrial, military, medical and domestic use, such as power transmission lines, mobile telephony, electronic security devices, etc. generate static and/or pulsed electric and magnetic fields [3] from low to very high frequency electromagnetic radiation [1,2]. Interaction with human beings can generate headache, anxiety, insomnia, cancerous tumors, Alzheimer and Parkinson diseases, etc [4]. Instead, static magnetic fields depending on the magnitude of the magnetic flux density [3] may affect the proper functioning of the human body, depending on the duration of their action. The static and/or pulsating magnetic field [5] induce electrical currents in metallic implants and affects pacemakers, endangering the health and even the lives of wearers.

Generally, the attenuation of the electromagnetic pollution level is achieved by the use of screens located in the area of pollution sources, which is a necessary but not sufficient condition to protect living organisms. Taking as model the clothing that gives human beings protection against the environmentally non-friendly factors, the new generation of clothes have to include also protection from electromagnetic pollution and/or to warn the human being when entering the areas with magnetic or electromagnetic risk factors.

Manufacturing of protective clothing requires the production of hybrid textile materials, known as smart textiles [6]. They are made of hybrid fibers containing aluminum wires [7], copper [8], silver [9] or graphene nanoparticles [10–12], ensuring good absorption of electromagnetic radiation. The later ones have a reduced specific mass compared to those made of metallic yarns and a high degree of shielding of electromagnetic radiation.

In order to fabricate devices that can be integrated into every-day clothing, we propose a relatively low-cost route as compared with semiconductor-based devices, to manufacture active magnetic fabrics (AMF). Relatively recently [13,14] AMF have been obtained with good absorption of the energy transported by microwaves, where cotton fibers were mixed with carbon microparticles [13], carbonyl iron and aluminum [14]. However, so far there are no references concerning the protection capabilities of AMF against the effects of the static magnetic fields.

In this paper, we present the fabrication process of a new class of magnetoactive tissues based on a cotton fabric (cloth) with simple weaving and a number of 45 cells/ mm^2. In the cloth is impregnated a magnetorheological suspension (MRS) containing a silicone oil (SO) matrix in which are dispersed carbonyl iron (CI) microparticles with

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volume fractions 1%, 2% and 4%. By using the plane (flat) capacitor method [15] together with models of dipolar approximations for linear continuous media, we study the influence of magnetic field and of the concentration of magnetic phase from MRS, on the relative dielectric permittivity ε', apparent viscosity η, the components of deformations ε_{xx} and tensions τ_{xx} and on the modulus of elasticity E. We develop a theoretical model in the framework of dipolar approximations which describes qualitatively the observed effects.

The obtained data can be used in fabrication of magnetic field sensors based on AMF. In particular, the dependence of the electrical and visco-elastic properties on the magnetic flux density and volume concentration of magnetic particles are useful for fabrication of capacitive sensors, and for modeling their time response when the input signals are of mechanical nature. An important application consists in issuing warnings to the wearers of cardiac pacemakers when they are found in regions of high magnetic flux densities such as those generated by home and/or industrial appliances.

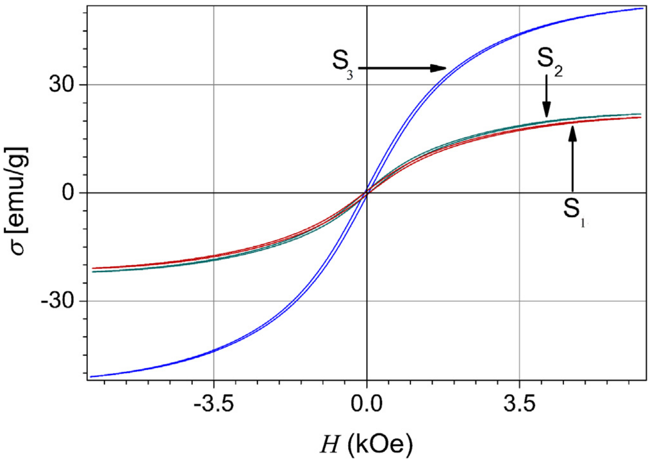

Fig. 1. Mass magnetization σ as a function of magnetic field intensity H for samples S^1, S^2 and S^3.

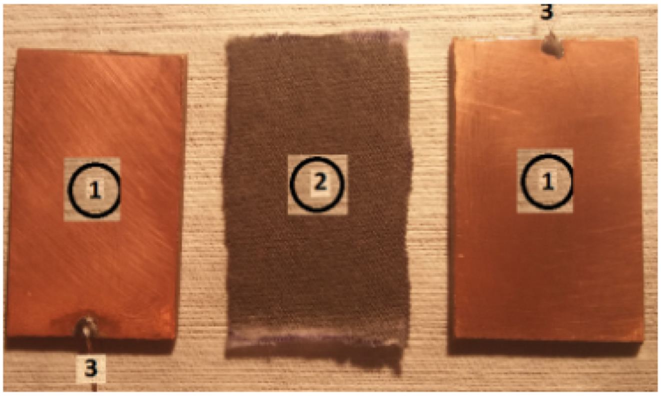

Fig. 2. The components of the flat capacitor (FC): 1 - Copper plate; 2 - Active magnetic fabric (AMF).

2. Materials and methods

2.1. The materials used for manufacturing AMF are

- CI powder (C-3518 type) from Sigma-Aldrich, with a diameter d between 4.5 and 5.4 μm, a minimum Fe content of 97 %, electrical resistivity 9.71 $\mu\ \Omega \times$ cm, and a density of 7.86 g/mL at 298 K. Elemental iron is produced by reduction of pentacarbonyl.
- SO (AP-200 type) with linear formula $[-Si(CH_3)_2\ O-\ ]_n$ from Sigma-Aldrich, with viscosity $\eta_{SO} = 200$ mPa × s at 300 K, density 0.967 g/mL at 293 K, useful for the preparation of oil baths having a temperature in the range of 223 ÷ 473 K.
- Cotton cloth from Latextile with plain weave bonding, a density of 0.37 g/cm^3 and a number of 45 cells/mm^2.

For manufacturing of AMF we perform the following steps: first, the CI powder mixed with SO (Table 1) is mechanically homogenized at 423 K for approximately 15 min. After this, the heating source is removed and the mixture is still continuously homogenized until the temperature of the mixture reaches room temperature. Initially, a liquid solution (MRSs) is formed, from which is retained a volume of 0.40 cm^3. Finally, this is impregnated in the cotton cloth and thus the magnetoactive tissue is obtained.

Magnetic measurements were performed under sine waveform driving field conditions by means of an laboratory-made ac induction hysteresis graph described in Ref. [16], and successfully applied for various systems [17]. The magnetic curves of AMF for samples S^1 and S^2 (Fig. 1) are approximately linear in the range $0 < H\,(\text{kOe}) < 2$, while for $H > 2$ kOe they approach saturation. For sample S^3 the saturation magnetization is achieved for $H \gtrsim 4$ kOe. The mass magnetization depends on volume concentration of CI and takes the values 18 emu/g for S^1, 20 emu/g for S^2, and 50 emu/g for S^3. Note that the areas delimited by the hysteresis curves are almost zero. This has in important advantage over other systems, such as in textiles based on $BaFe_{12}O_{19}$ [18] where the area delimited by hysteresis curves is large and thus the response function of the device is non-linear with magnetic field intensity.

Table 1
Composition of MRSs samples and the volume fractions of CI from AFM.

S_i	SO (cm^3)	CI (cm^3)	Φ_{CI}(%)
S_1	1.98	0.02	1
S_2	1.96	0.04	2
S_3	1.92	0.08	4

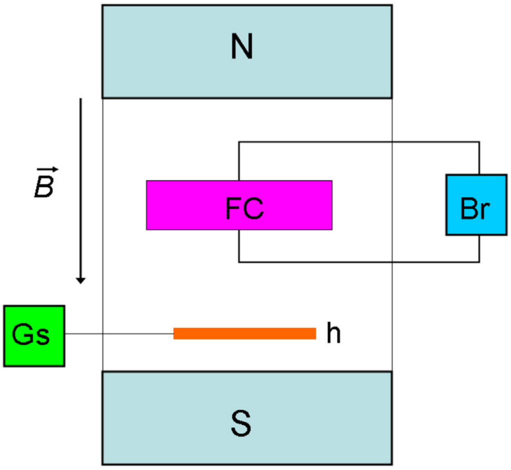

Fig. 3. Experimental setup (ensemble configuration): N and S - electromagnet's poles, Br - RLC bridge, Gs - Gaussmeter, h - Hall probe, FC - flat capacitor, $\vec{B}$ - magnetic flux density vector.

Electrical and visco-elastic properties are obtained by using an experimental setup (Fig. 3) which consists from an electromagnet powered by a source of continuous current (RXN-3020D) from Electronix Co. Ltd. (not shown in Fig. 3), a gaussmeter Gs (DD-102 type) from Dexing Magnet and the bridge Br (8846A type) from Fluke. The capacitor FC, whose components are shown in Fig. 2 is fixed between the magnetic poles N and S on the hall probe. Magnetic flux density B is measured with Gs and the response function of FC under the influence