Budapest University of Technology and Economics
Department of Physical Chemistry
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PhD Theses

Effect of the magnetic field on the elasticity of composite gels and elastomers

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Introduction

The research in the field of functional materials was stimutated by the expanding use of structural materials and new customer needs. Special attention was paid to polymers which have tunable physico-chemical properties in external electric or magnetic fields.

In the Laboratory of Soft Matters at the Department of Physical Chemistry, BME under the leadership of Prof. Miklós Zrínyi magnetic polymergel, a novel composite material has been developed. This magnetoelastic material contains magnetic micro or nanoparticles in a highly elastic matrix. In a properly chosen external magnetic field this polymer can be elongated, bent, rotated or contracted.

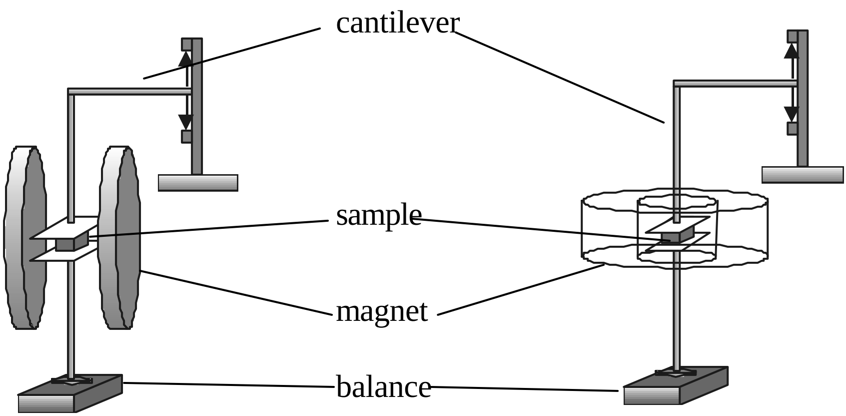
The aim of my work in the group was to optimize the influence of the external magnetic field on the elastic modulus of isodimensionally filled poly(dimethyl-siloxane) (PDMS) elastomers.

Isotropic and anisotropic magnetoelastomers of different cross-link density were synthesized. Carbonyl iron and Fe_2O_3 particles were used as fillers.

The influence of the external magnetic field on the elastic modulus was systematically investigated in different experimental arrangement to reveal the role of the relative orientation of the magnetic field, the alignement of the particle aggregates and the direction of the deformation

Experimental methods

In order to measure the elastic modulus in magnetic field, I developed two apparatuses. Their scheme are shown in the figure.



The elastic modulus was derived from the neo-Hook equation:

$$s_n = \frac{F_x}{A_0} = G(l_x - \frac{1}{l_x^2})$$

, where σ_n is the nominal stress, F_x is the force acting along the x-axis , A_0 is the surface area of the sample - perpendicular to F_x, G is the elastic modulus and ?$_x$ is the deformation in the x direction.

New scientific results

1. I prepared carbonyl-iron and Fe_3O_4 (Bayferrox 318M) loaded isotropic and anisotropic elastomers. It was concluded that their magnetic field induced elastic modulus depends on the direction of the deformation and the magnetic field applied, as well as the particle pattern developing in the network. (In case of anisotropic elastomers it depended on the orientation of the particle structure and the direction of the external magnetic field.)

2. Investigating the elastic modulus of the carbonyl-iron and Fe_3O_4 (Bayferrox 318M) loaded isotropic elastomers I pointed out, that in the case of the carbonyl-iron loaded elastomers the increase in the elastic modulus due to the external magnetic field was larger if the applied force was perpendicular to the external magnetic field than in the case of parallel relative orientation. In case of the Fe_3O_4 loaded elastomers the improvement in the magnetic field induced elastic modulus was the highest when the applied force and the external magnetic field were parallel to each other. The difference between the two fillers can be explained by the different magnetic and interfacial properties of the particles.

3. From the experimental results I concluded, that when the applied force was perpendicular to the external magnetic field, the highest increment in the magnetic field induced elastic modulus of the carbonyl-iron and Fe_3O_4 (Bayferrox 318M) loaded anisotropic elastomers was obtained when the direction of the external magnetic field was parallel to the particle formation. On the other hand, the increment in the elastic modulus due to the external magnetic field was the lowest when the direction of the magnetic field was perpendicular to the particle chains and to the applied force.

4. According to the experimental results I concluded, that when the applied force was parallel to the external magnetic field, the highest increment in the magnetic field induced elastic modulus of the carbonyl-iron and Fe_3O_4 (Bayferrox 318M) loaded anisotropic elastomers was obtained when the direction of the external magnetic field was parallel to the applied force. I concluded that the increment in the elastic modulus due to the external magnetic field was the highest in this case compared to any other direction.

5. It was concluded that the in of the carbonyl-iron loaded elastomers already small deformation parallel to the aligned particles breaks the particle chains. The value of the deformation force in this point was characteristic to the sample. In case of the Fe_3O_4 (Bayferrox 318M) particles, the compression did not lead to the break-down of the particle alignments, as they bent when the anisotropic elastomer was compressed.

6. A phenomenological expression was developed to describe the relationship between the elastic modulus on the magnetic induction for the carbonyl-iron and Fe_3O_4 (Bayferrox 318M) loaded isotropic and anisotropic elastomers. Within the

experimental accuracy the prediction of the phenomenological equation was supported by the experimental data.

7. I investigated the increment of the elastic modulus ($G_{M,\infty}$) with increasing concentration of the filler particles. Within the experimental accuracy, a linear relationship can be used. The rate of the increment depended on the cross-linker content, on the direction of the force, on the particle formation in the network and, in the case of the anisotropic samples, it also depended on the direction of the particle formation and the direction of the external uniform magnetic field.

Possible practical applications

I concluded that the elastic modulus of the magnetoelastomers can be increased by applying external magnetic field. This temporary reinforcement lasts as long as the magnetic field acts on the magnetic elastomer.

Recently it became an intensively studied field of research to develop so called intelligent shock-absorbers, where during operation the stiffness can be controlled by external stimuli.

Based on my results, these magnetic polymers are suitable magnetic field controllable shock absorber.

Publications

Publications relevant to the thesis:

1. **Zsolt Varga**, József Fehér, Genovéva Filipcsei and Miklós Zrínyi:
   Smart Nanocomposite Polymer Gels
   Macromolecular Symposia, 200, 93-100 (2003)

2. **Zsolt Varga**, Genovéva Filipcsei, Miklós Zrínyi:
   Smart Composites with Controlled Anisotropy
   Polymer, *46 (18), 7779-7787* (2005)

3. **Zsolt Varga**, Genovéva Filipcsei, András Szilagyi and Miklós Zrínyi:
   Electric and Magnetic Field Structured Smart Composites
   Macromolecular Symposia, *227, 123-133 (2005)*

4. **Zsolt Varga**, Genovéva Filipcsei and Miklós Zrínyi:
   Magnetic Field Sensitive Functional Elasztomers with Tuneable Elastic Modulus
   Polymer, (accepted)

Further publications:

5. **Varga Zsolt**, Filipcsei Genovéva, Zrínyi Miklós:
A XXI. század új kihívása: Az intelligens anyag (elso rész),
Természet Világa 2004. september 386-388.

6. Fehér József, Szilágyi András, **Varga Zsolt**, Filipcsei Genovéva és Zrínyi Miklós:
Elektromos térre érzékeny folyadékok és elasztomerek I.
Magyar Kémiai Folyóirat

Conference lectures

1. **Varga Zsolt**, Zrínyi M.:
Különleges Tulajdonságú Szilikon Elasztomerek és Vizsgálatuk
INSTRON Nap, Miskolctapolca, 28. april 2004.

2. **Varga Zsolt**: Intelligens polimer kompozitok kontrollált anizotrópiával
Vegyészmérnöki Kar 2. doktoráns konferencia,
24. november 2004.