Budapest University of Technology and Economics
Department of Physical Chemistry

ELECTRO-RESPONSIVE GELS AND ELASTOMERS

PhD Theses

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SUMMARY

Nowadays one of the most interesting scientific tasks is to develop so-called smart materials. The expression “smart material” (even called “intelligent”, “smart”, “responsive” and “adaptive”) is rather new as it appeared first in the beginning of the 1980s (see references 1-6). One the meanings of the word “intelligence” is the ability to adapt to different situations. This is the main cause why we can speak about the intelligence of non-living materials.

Development of the so-called “functional materials” was initiated by the need of new structural materials and rather special industrial expectations and goals. Nowadays the main directions of materials science is the development of materials that mimic some biological functions and abilities. The cause is simple: living materials are generally more efficient and environmentally friendly. The final goal of scientific research similar to that reported in these theses is to make materials, that combine some properties of other living or non-living materials. This way we can make things that show behaviours and abilities newer seen before.

Main properties of usual structural materials (stone, metals, wood, glass, plastics) are high mechanical stability, rigidity and low water contents. It means that these materials remarkably differ from living gel-like materials (heart-muscles, eyes, nails), that are wet, soft and able to adapt to the changes in the environment. After that it is not surprising that gels form one if the main groups of smart materials [7,8]. Different polymer gels are used in biology and surgery (controlled drug delivery), it was possible to make artificial muscles (linear actuators) that move robots, and there are different biomimetic energy converters and separation techniques. Polymer gels are exceptional even among smart materials, as they can be made sensible for many different environmental changes. These stimuli can be the change of pH, the concentration, or the composition of the swelling liquid, or even the change of the intensity of light falling on the gel [9-14]. Electric and magnetic field-sensitive gels are especially important, as changes of these stimuli can be fast and accurately regulated.

Changes in these fields makes it possible to modify the state of equilibrium between the gel and its environment into the proper direction, without any physical contact.

Recently the research group of Prof. Miklós Zrínyi (Department of Physical Chemistry, Technical University of Budapest) have developed a smart gel system responsive to magnetic fields. This is the so-called “ferrogel”, that consists of a polymer matrix swollen by a magnetic liquid. The “ferrogel” can be highly deformed by a permanent- or electromagnet, and can produce various equilibrium shapes depending on the geometry and strength of the field. It can bend, stretch, contract, and can be moved or rotated [15,16]. The change of shape is fast, great, and reproducible, and does not cause any permanent change in the gel.

I have attended to this group (Group of Soft Materials) three years ago. My task was to prepare and investigate the electrical analogue of the “ferrogel”. It was found, that swollen silicone rubbers filled with colloid particles with high dielectric constant show the same smart properties as the ferrogel. Properties of such materials meet the practical industrial needs.

During my work above the development of the proper preparation technique I have built a highly stabilized, low energy power supply that can output even 20000 V by using only three commercially accessible batteries. With the aid of this apparatus I have studied the behavior of the above mentioned gel systems in different electric fields. Based on the findings of detailed experiments I have developed a mathematical model for the kinetics of deformation of the gels.

THESES

1. Chain like aggregates of titan-dioxide and iron (so-called "carbonyl iron") particles in silicone oil has been immobilised in chemically cross-linked poly(dimethyl-syloxane) gels. Aggregation was provoked by electrorheological (ER) and magnetorheological (MR) effects. Aggregates pointing into the direction of the outer electric or magnetic field caused strong mechanical and swelling anisotropy in the elastic rubber phase.

2. It was found, that deformation of the systems containing iron particles can be followed through measurement of the current in a weak electric field. This property makes it possible to produce self-monitoring elastic systems.

3. Samples containing anatase (TiO_2), magnetite and iron particles in poly(dimethyl-syloxane) matrix were sensible for outer electric field. I have proven that deformation of these systems in electric field is caused exclusively by the filling material. In case of a pure gel no deformation was found in the same situation.

4. All the above mentioned samples have shown strong and fast deformation that always pointed into the direction of the cathode. Deformation was studied at different field strengths with different filling materials and different concentrations. It was found, that below of 1,6 kV/cm field strength deformation of a cylinder shaped sample is proportional to the square if the field strength.

5. Deformation on all samples highly depends even on time. Kinetic studies has shown that the equilibrium shape was reached in 5 minutes independent of the filling material. The logical explanation of this delay can not be purely the slowdown caused by the viscosity of the silicone oil matrix, as its duration is too high.

6. I have developed a theoretical model for the description of deformation found in electric field. The model is based on the assumption that this deformation is caused by the charge emitted by the filling particles at high voltages. By this mathematical model it was possible to determine the net charge of different samples. It falls into the order of 10^{-10} C, depending on the size and composition of the gel cylinder.

7. In case of samples containing anatase (TiO_2) it was possible to perform directed deformation with specially shaped electrodes. These electro-responsive elastomers can show various even very sophisticated deformations, that can be controlled through the strength and geometry of the outer electric field.

8. I have developed a general method and machinery for investigation of the above described smart elastomers. I have built a highly stabilized, low energy power supply that can output even 20000 V by using only three commercially accessible batteries. With different electrodes it can produce homogeneous and inhomogeneous electric fields with accurately regulated strengths.

PUBLICATION LIST

CHAPTERS IN BOOKS

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3. M. Zrínyi, D. Szabó, **J. Fehér**: *Comparative Studies of Electric and Magnetic Field Sensitive Polymer Gels*, **Smart Structure and Materials** 1999, Part of the SPIE Conference on Electroactive Polymer Actuators and Devices
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2. M. Zrínyi, **J. Fehér**, G. Filipcsei: *Novel Gel Actuator Containing TiO_2 Particles Operated Under Electric field,* **Macromolecules**, Vol. 33, No. 16, p. 5751-5753 (2000)
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