CPP 5: Polymer Networks and Dynamics I: Elastomers and Magnetic Materials

Time: Monday 10:15–13:00 Location: ZEU 255

Invited Talk CPP 5.1 Mon 10:15 ZEU 255

A Combined Rheological and Dielectric Analysis of Filler Networking in Elastomer Nano-Composites — •Manfred Klüppel — Deutsches Institut für Kautschuktechnologie e.V., Eupener Str. 33, D-30519 Hannover, Germany

The dynamics of filler networking (flocculation) in carbon black filled elastomer composites is investigated by dielectric relaxation spectroscopy during oscillatory shearing in a plate-plate rheometer. It is demonstrated that during heat treatment at low strain amplitude, a pronounced filler networking takes place in rubber melts leading to a simultaneous increase of the shear modulus and dc-conductivity. Two relaxation times, obtained from a Cole-Cole fit of the dielectric spectra, are identified, which both decrease strongly with increasing flocculation time. This behavior is analyzed in the frame of fractal network models. During filler networking, a universal scaling behavior holds between the conductivity and the corresponding high frequency relaxation time, which fits all the measured data. It is demonstrated that the underlying basic mechanism is a change of the correlation length of the filler network, i.e. the size of the fractal heterogeneities. This decreases during filler networking due to the formation of additional conductive paths. The same universal scaling behavior is found for temperature dependent dielectric measurements of the cured systems, which are heated from room temperature up to 200 °C. Thereby, the conductivity decreases and the relaxation time increases, indicating that the filler network breaks up randomly due to the thermal expansion of the rubber matrix.

CPP 5.2 Mon 10:45 ZEU 255

Investigation of strain induced crystallization of natural rubber under cyclic impact loading — •Konrad Schneider — Leibniz-Institut für Polymerforschung Dresden, Hohe Str. 6, 01069 Dresden, Germany

Strain induced crystallization (SIC) is one of the special features of natural rubber (NR), responsible for its outstanding mechanical performance. Nevertheless, for short term behaviour of NR, e.g. within a rolling tire, the dynamic of SIC plays an important role. By means of synchrotron x-ray scattering SIC is monitored during impact loading together with recording energy dissipation by thermography. The results enable a more realistic modelling of the dynamic behaviour of natural rubber.

CPP 5.3 Mon 11:00 ZEU 255

Nano-mechanical imaging reveals heterogeneous cross-link distribution in sulfur-vulcanized butadiene-styrene rubber comprising ZnO particles — Yulia Glebova[1,2], •Valentin Reiter-Scherer[1], Sari Suvanto[3], Tarmo Korpela[3], Tuula T. Pakkanen[3], Nikolai Serverin[1], Vladimir Shershnev[2], and Jürgen P. Rabe[1] — [1]Department of Physics and IRIS Adlershof, Humboldt-Universität zu Berlin, Germany — [2]Moscow State University of Fine Chemical Technologies, Russia — [3]Department of Chemistry, University of Eastern Finnland, Finnland

The addition of zinc oxide (ZnO) to sulfur (S-) vulcanized rubbers is known to accelerate the cross-linking kinetics and to increase the heterogeneity of the cross-link density. However, the spatial distribution of cross-links is hardly known and the mechanism of the activity of ZnO is disputed. We therefore investigated S-vulcanized butadiene-styrene rubber comprising ZnO particles. The samples were fractured and then investigated employing the nano-mechanical mapping mode (NM) of scanning force microscopy (SFM), supported by scanning electron microscopy (SEM). We find that rubber around the ZnO particles exhibits a higher Young's modulus in a shell with a width up to about 200 nm. Furthermore, the extension and retraction curves on these shells exhibit a smaller hysteresis than on the rubber further away from the ZnO particles. We attribute the higher Young's modulus and the smaller hysteresis to a higher cross-link density in rubber surrounding the ZnO particles and we discuss a mechanism of the activity of ZnO in rubbers which can explain this.

CPP 5.4 Mon 11:15 ZEU 255

Force-induced matrix-mediated interactions between rigid inclusions in elastic media — Mate Puljiz[1], Shilin Huang[2], Günter K. Auernhammer[2], and •Andreas M. Menzel[1] — [1]Heinrich Heine University Düsseldorf, Düsseldorf, Germany — [2]Max Planck Institute for Polymer Research, Mainz, Germany

The situation of forces acting on rigid inclusions in elastic matrix environments is addressed. These forces can be imposed from outside, or they are induced between the inclusions, if, for example, external electric or magnetic fields generate interacting electric or magnetic moments in the inclusions. Resulting translations of the inclusions distort the embedding elastic matrix, which gives rise to long-ranged matrix-mediated interactions between the inclusions.

We demonstrate that these induced interactions can be calculated analytically in the case of rigid spherical inclusions [1]. For this purpose, a formalism used to capture hydrodynamic interactions between particles in colloidal suspensions [2] is adapted to the situation of an elastic environment. Experiments on rigid magnetic particles in a soft elastic gel matrix confirm our approach [1]. The description is readily extended to include induced torques [3].

Our results will be important in the future to characterize, for instance, the external tunability of mechanical properties in electric or magnetic composite materials, and for microrheological applications.

[1] Puljiz et al., *Phys. Rev. Lett.* (accepted, 2016).
[2] Dhont, *An Introduction to Dynamics of Colloids* (Elsevier, 1996).
[3] Puljiz et al., *arXiv preprint* arXiv:1611.08823 (2016).

CPP 5.5 Mon 11:30 ZEU 255

Cyclic adjustable nanometer sized ion tracks in Polydimethylsiloxane — •Calvin Brett[1,2,3], Wiebke Ohm[1], Matthias Schwartzkopf[1], Pablo Mota-Santiago[2], Daniel Severin[4], Nigel Kirby[5], Christina Trautmann[4,6], Patrick Kluth[2], Michael A. Ruebhausen[3], and Stephan V. Roth[1,7] — [1]DESY, Notkestr. 85, D-22607 Hamburg — [2]Australian National University, Canberra, ACT 2601 — [3]University of Hamburg, Luruper Chaussee 149, 22761 Hamburg — [4]GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt — [5]Australian Synchrotron, 800 Blackburn Road, Clayton — [6]Technische Universität Darmstadt, Alarich-Weiss-Straße 2, 64287 Darmstadt — [7]KTH, Teknikringen 56-58, SE-100 44 Stockholm

The efficiency of miniaturization crucially relies on the ability to tailor complex systems on the nanoscale. We used swift heavy ion irradiation as a tool to yield highly controllable nanometer sized features. Hence, we studied the structure and morphology of irradiated Polydimethylsiloxane (PDMS) thin films by means of small angle x-ray scattering (SAXS) and infrared spectroscopy. We found first evidence of ion tracks in silicon based polymers. Furthermore, in situ stretching experiments using SAXS show the appearance of cyclic elastically deformable ion tracks in PDMS. This offers adjustable nanostructures for new applications.

15 min break

CPP 5.6 Mon 12:00 ZEU 255

Switchable nonlinear stress-strain properties and dynamic behavior of magnetic gels — Peet Cremer, Giorgio Pessot, Hartmut Löwen, and •Andreas M. Menzel — Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany

Magnetic gels, ferrogels, and magnetorheological elastomers consist of magnetic colloidal particles embedded in a permanently crosslinked, possibly swollen, elastic polymer matrix. Many of their material properties can be reversibly switched from outside using magnetic fields.

Two of such switchable features are presented and analyzed. First, these are nonlinear stress-strain properties of materials containing chain-like particle aggregates [1,2]. We had previously identified intermediate plateau-like regimes on the stress-strain curves that are tunable by external magnetic fields [1]. Now, we report on the effect of different magneto-mechanical couplings between the magnetic moments and the elastic matrix that qualitatively influence the overall behavior [2]. Second, we determine linear dynamic properties, starting from mesoscopic particle-based models [3]. We analyze the influence of different particle arrangements and magnetic interactions on the linear dynamic storage and loss moduli. Depending on the frequency of the stimulus, qualitatively different trends are observed.

Both aspects are important for the application of magnetorheological gels and elastomers, e.g., as soft actuators or tunable dampers.

[1] Cremer et al., *Appl. Phys. Lett.* **107**, 171903 (2015).
[2] Cremer et al., *Phys. Chem. Chem. Phys.* **18**, 26670 (2016).
[3] Pessot et al., *J. Chem. Phys.* **145**, 104904 (2016).

CPP 5.7 Mon 12:15 ZEU 255

The Dipolar Mean Field Model: A promising Ansatz to describe Magneto-Sensitive Elastomers — •Dirk Romeis and Marina Saphiannikova — Leibniz-Institut für Polymerforschung Dresden e.V., D-01069 Dresden, Germany

Magneto-sensitive elastomers are composed of magnetizable microparticles embedded into a soft-elastic polymer network. In the presence of an external magnetic field these composites can change their mechanical properties significantly. The precise relations and conditions responsible for the actual changes are not fully understood, neither experimentally nor theoretically. Recently, we developed a dipolar mean field approach [1] to describe the effective behavior of such composites in the macroscopic limit. The approach itself provides a very efficient calculation method for various situations and it is partially even analytically solvable. This allows a comprehensive understanding of the mechanisms underlying the behavior of magneto-sensitive elastomers and we are able to predict a discontinuous shape change for very oblate samples. It will also be shown, that the results for the case of a random isotropic distribution of magnetizable particles in the elastomer are in quantitative agreement with a micro-scale continuum model [2].

Literature
[1] *Romeis D. et. al.* Soft Matter **12**, 9364-9376 (2016)
[2] *Metsch P. et. al.* Comp. Mat. Science **124**, 365-374 (2016)

CPP 5.8 Mon 12:30 ZEU 255

Investigation of coated magnetic nanoparticles in polymer matrix via small-angle scattering methods — •Lisa Fruhner, Margarita Krutyeva, Wim Pyckhout-Hintzen, and Jürgen Allgaier — Forschungszentrum Jülich GmbH, Jülich Centre for Neutron Science (JCNS-1) & Institute of Complex Systems (ICS-1), 52425 Jülich

Bringing magnetic nanoparticles into polymer matrices allows the creation of functional nanocomposites which offer a broad application range from sensors through electronics to smart coatings and human health. It is of great importance to be able to efficiently control the encapsulation and synthetic conditions regarding the minimization of agglomerates and creation of uniform hybrid nanomaterials

By making use of sophisticated synthesis techniques we obtain spherical nanoparticles in different size ranges with a small polydispersity. These nanoparticles are coated with a crosslinked shell consisting of the matrix polymer what allows them to be easily dispersed into the matrix and protects them against agglomeration.

Investigations via small-angle scattering methods and electron microscopy reveal the presence of mostly single nanoparticles and a small amount of linear chains consisting of a few particles. These systems are used as a basis for magneto-elastomeric nanocomposites with the structure controlled by mechanical or magnetic forces.

CPP 5.9 Mon 12:45 ZEU 255

Modeling bidisperse soft magnetic elastomers — •Pedro A. Sánchez[1], Sofia S. Kantorovich[1,2], Oleg V. Stolbov[3], and Yuriy L. Raikher[3] — [1]Computational Physics, University of Vienna, Sensengasse 8/18, 1090 Vienna, austria — [2]Ural Federal University, 3 Ural Federal University, Lenin av. 51, Ekaterinburg, 620000, Russia — [3]Institute of Continuous Media Mechanics, Ural Division of RAS, 1 Korolyov street, Perm, 614013, Russia

Soft magnetic elastomers are a type of hybrid materials consisting of a soft matrix of polymers in which a high volume fraction of magnetic micro- and/or nanoparticles are embedded. The elastic modulus of the polymer matrix is low enough to allow strong structural changes in the system induced by the response of the magnetic particles to external magnetic fields. These novel materials are promising candidates for a broad range of applications, like magnetically controlled dampers, magnetic field sensors, flow regulators or microfluidic pumps.

Here we present a bead-spring model of a soft magnetic elastomer material in which a combination of two types of magnetic particles are present within the polymer matrix: a low volume fraction of magnetically hard colloids—typically, ferromagnetic particles with diameters of 3-5 μm—and a high volumen fraction of weak magnetic particles—typically paramagnetic particles with a diameter of around 10nm. We analyze the magnetic response of this system by means of extensive computer simulations, and connect our results to analytical models based on continuum approaches.