TENSILE MODULUS OF A MAGNETORHEOLOGICAL ELASTOMER: EXPERIMENTS AND MICROSCOPIC MODELING

D. Yu. Borin[1], F. Adam[1], D. Ivaneyko[2], V. Toshchevikov[2], V. Bogdanov[3], G. Stepanov[4], M. Saphiannikova[2], S. Odenbach[1]

1 - Institute of Fluid Mechanics, TU Dresden, Germany
2 - Leibniz Institute of Polymer Research, Dresden, Germany
3 - Technical State University "MAMI", Moscow, Russia
4 - State Scientific Center RF GNIIChTEOS, Moscow, Russia

dmitry.borin@tu-dresden.de

Magnetorheological elastomers are smart composites of magnetic particles embedded in an elastic polymer matrix. Depending on the synthesis method of the composites the spatial distribution of particles in the matrix can be either isotropic or anisotropic, if a magnetic field was applied before the cross-linking process [1]. Furthermore, it is potentially possible to provide certain patterns of particles inside the matrix, using rotating magnetic fields or a strong shear flow before the cross-linking procedure [2]. Generally, experimental tests show an increase of the elastic modulus of the magnetorheological elastomer with increasing magnetic field [3]. However, most experimental studies are dealing with shear deformations using oscillatory tests. In our experimental setup the composite was stretched along the direction of the applied magnetic field and the obtained results differ from the results of oscillatory tests. A maximum of the tensile modulus occurs at deformations of 1-2 %. With further increase of the strain amplitude the tensile modulus reaches values which are almost equal to the modulus of the sample in zero field. Moreover, in compression tests of the composite, performed by front impact, a decrease of the decrement of oscillation has been found for the sample influenced by an applied magnetic field. From mechanical point of view this behavior expresses the evidence of a decrease of the tensile modulus. On the other hand, in experiments on free vibrations [4] it has been found that the damping factor is independent on the applied magnetic field. To shed a light on this behavior and to give at least a qualitative explanation, a microscopic model of the composite has been developed. This model is based on minimization of the free energy, considering a linear approximation for the elasticity of the polymer matrix and dipole-dipole interaction between the magnetic particles. Diverse patterns of particles can be taken into account. In contrast to former publications [5] we consider the composite as a heterogeneous medium and the investigation is not confined to the calculation of the shear modulus only. The results of the calculations basically confirm the experimental observations and stimulate further studies. It has been found that the shear modulus increases for all types of distribution of the magnetic particles. The tensile modulus decreases for samples with chain-like structures. For the sample with isotropic distribution of the magnetic particles the tensile modulus slightly increases with increasing magnetic field. For the planar patterns of the powder the tensile modulus noticeably increases and this fact has to be examined experimentally. The next step for a further model development is the use of a neo-Hookean approach and consideration of the tensile modulus in the range of very small deformations, where the maxima have been observed experimentally.

This project is partially funded by the European Union and the Free State of Saxony.

[1] M. Jolly, D. Carlson, B. Munoz, T. Bullions 1996 J. Intel. Mater. Syst. Struct. 7 p. 613-22
[2] V. G. Kulichikhin et al 2009 Polymer Science Ser. A 51 (11-12) p. 1303-12
[3] W. H. Li, Y. Zhou, T. F. Tian 2010 Rheol Acta 49 p. 733–40
[4] G. Y. Zhou 2003 Smart Mater. Struct. 12 p. 139-46
[5] L. Borcea, O. Bruno 2001 J. Mech. Phys. Solid 49 p. 2877-919