EXPERIMENTAL CHARACTERIZATION OF MAGNETOElastomers AND DETERMINATION OF MATERIAL MODEL PARAMETERS FOR SIMULATIONS

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1. Introduction

To assess the applicability of magnetic metallic particle filled soft polymeric materials (i.e. gels and elastomers, termed as magnetoelastomers) for practical industrial applications, comprehensive characterization of the mechanical behaviour is essential.

For this study Polydimethylsiloxane (PDMS) was selected as matrix-material. Iron particles of various shapes (aspect ratios) and surface treatments were added as fillers in various amounts. Isotropic specimens were prepared and subjected to dynamic mechanical measurements in presence or absence of homogeneous magnetic fields. In order to achieve the necessary field homogeneity in the region of the test specimen, novel set-ups were developed using magnetostatic simulation software and rapid prototyping tools.

2. Experimental Setup – Design and Development

The elastomer specimens were tested with a BOSE Electroforce test bench. To allow for experiments in homogeneous magnetic fields as well, a novel setup had to be designed, that could be used in conjunction with the existing system. In terms of size and ease of use, a straightforward approach is to generate the field by installing two NdFeB permanent magnets, one on each side of the specimen. The optimal magnet dimensions for achieving maximum field homogeneity at a given distance (specimen size plus some space for clamping and loading strain) were calculated using magnetostatic simulation software (Ansoft Maxwell). For two NdFeB disks of 15 cm diameter and 1 cm thickness at a distance of 7 cm, a quasi homogeneous field of 107.2 mT in the specimen region is predicted (Fig. 1).

![Calculated flux lines and flux density of magnets used in test bench](image)

This was checked experimentally via teslameter measurements, the deviations were indeed less than 1% with an average flux density of 117 mT. The jackets for attaching the magnets onto the test bench and the specimen clamps were designed in CAD software, then printed with a Stratasys FDM system (Fig. 2).

![a) CAD-Model, b) printed parts](image)

3. Specimen Preparation

For this study PDMS was compounded with different types of iron particles.

The following parameters were varied:
- cross link density of the PDMS matrix (various amounts of X-linker added)
- filler content
- particle shape (aspect ratio, AR)
- particle surface treatment (unmodified, silica coating, silanized SiO\textsubscript{2} coating)
From these mixtures cylindrical specimens were prepared using casting moulds made of PTFE and cured for 24 h at room temperature.

4. Experimental Results

The influence of filler content and filler aspect ratio on the elastic properties was investigated and compared to micromechanical simulations (Fig. 3) using a mean-field homogenization scheme (Digimat, e-Xstream, Foetz, LX) [1].

![Fig. 3: Experimental and simulated stiffness values of PDMS with iron filler (various amounts and AR)](image)

The dynamic mechanical behaviour of PDMS specimens containing particles with various surface treatments (uncoated, SiO$_2$ coating, silanized SiO$_2$ coating) was determined (Fig. 4).

![Fig. 4: Frequency dependent storage modulus of PDMS (5% X-linker) with various surface treated particles (10% filler content, AR1)](image)

While the uncoated particles gave the expected increase in stiffness (80% up), the surface treated particles caused the PDMS-matrix to soften drastically (SiO$_2$: 92.5% down, SiO$_2$/Silane: 74% down).

Furthermore the stiffness change caused by a magnetic field aligned in loading direction was studied (Fig. 5). This effect can be quantified through the magnetic stiffening factor (MSF) [2].

$$MSF = \frac{E_{MF}'}{E_0}$$

![Fig. 5: Storage modulus and MSF of PDMS with various X-linker conc. and 10% Fe (uncoated, AR1)](image)

The application of a magnetic field increased the stiffness of all specimens, at which an inverse correlation between matrix-stiffness and MSF was found. For the very soft elastomers containing the coated particles, this effect was even more pronounced (up to 300% increase).

Future work will focus on the development of a procedure for processing particle filled elastomers in magnetic fields to achieve particle distributions of controlled anisotropy as well as compounding magnetic particles with different elastomer matrices (Acrylic elastomers, thermoplastic elastomers) to cover a wider range of viscoelastic properties.

5. Acknowledgements

The research work of this paper was performed in the KAPMT project with contributions by Altana Eckart (Velden, D). The KAPMT is funded by the Austrian Government and the State Government of Upper Austria.

References