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 rheological and 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 rheological and dynamic mechanical measurements in presence or absence of homogeneous magnetic fields. In order to achieve the necessary field homogenity 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. To keep it small and easy to use, it was decided 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 (Maxwell). For two NdFeB disks of 15 cm diameter and 1 cm thickness at a distance of 7 cm, a quasi homogeneous field of 103.5 mT in the specimen region is predicted (fig. 1).

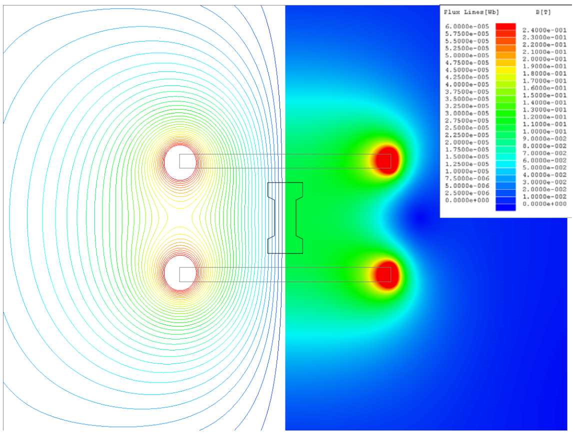

Fig. 1: Calculated flux lines and flux density of magnets used in test bench

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).

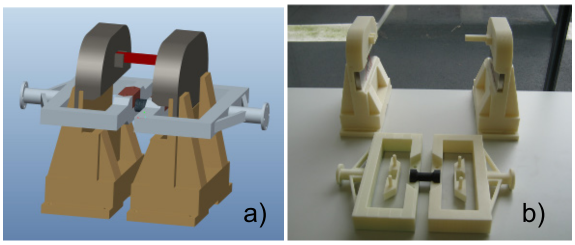

Fig. 2: a) CAD-Model, b) printed parts

Additionally a steel frame was constructed to bring the test bench into an upright position, thus avoiding any bending force acting upon the load cell. The finished experimental setup is displayed in figure 3.

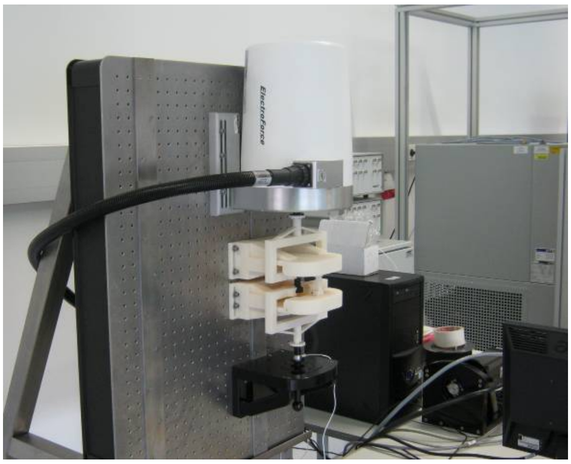

Fig. 3: Experimental setup

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_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 dynamic mechanical behaviour of PDMS specimens containing particles with various surface treatments (uncoated, SiO_2 coating, silanized SiO_2 coating) was investigated.

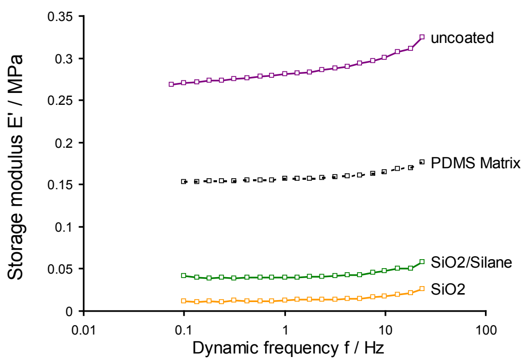

Fig. 4: Frequency dependent storage modulus of PDMS (5% X-linker) with various surface treated particles (10% filler content, AR1) (r)

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 quanti-fied through the magnetic stiffening factor (MSF) [1].

$$MSF = \frac{E'_{MF}}{E'_0}$$

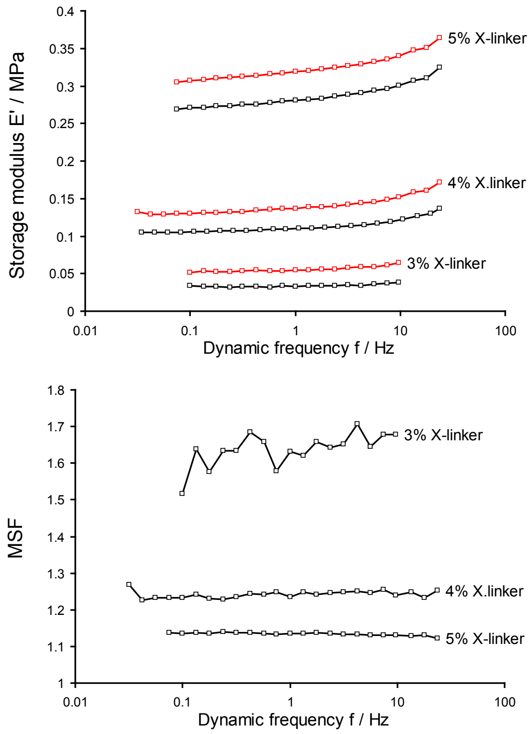

Fig. 5: Storage modulus and MSF of PDMS with various X-linker conc. and 10% Fe (uncoated, AR1)

The application of a magnetic field increa-sed 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 (Acrlyic elastomers, Engage type thermoplastic elastomers) to cover a wider range of viscoelastic properties.

References

[1] Major Z., Schrittesser B., Filipcsei G.: Characterisation of dynamic mechanical behaviour of magnetoelastomers; Plastics, Rubber and Composites, vol.38, p.313 (2009)