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MANUFACTURE AND TESTING OF ANISOTROPIC MAGNETORHEOLOGICAL ELASTOMERS

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Abstract: *The purpose of this paper was to present the manufacturing process of magnetically polarized (anisotropic) magnetorheological elastomers (MRE) and to investigate their magnetomechanical properties. The materials were based on a thermoplastic matrix, iron particles and additives which improved the plasticity of a resulting composite. A procedure was developed to create specimens with magnetic field-oriented microstructure. MRE with various chemical compositions were subjected to cyclic shearing with the use of a dedicated test stand. The results revealed that selected properties of magnetorheological elastomers differ markedly depending on the plasticity of the matrix.*

Key words: *MRE, SMART materials, experimental mechanics, damping.*

1. Introduction

Magnetorheological (MR) materials are materials whose selected properties can be changed by an external magnetic field. They belong to a wider material group known as Smart Magnetic Materials (SMM). MR materials are usually divided into magnetorheological fluids (MRF) and various types of magnetorheological composites.

Magnetorheological elastomers (MRE) are new MR composites which comprise a non-magnetic polymer matrix, magnetically active particles and optional additives. The application of an external magnetic field causes interparticle attractions, which changes properties of the whole composite. This change in properties is reversible and is known as the magnetorheological effect.

The cross-linked structure of the matrix ensures that particles maintain their positions within the composite. There are two basic types of MRE depending on the particle arrangement in the matrix. In isotropic magnetorheological elastomers the magnetic particles are dispersed uniformly within the matrix. In the case of anisotropic (polarized) MRE the particles are oriented by a magnetic field which is applied before the matrix is fully cured. This results in the anisotropy of selected properties [1].

2. Objectives

The main goal of this paper was to show the manufacturing process of anisotropic MR elastomers with different chemical compositions and to examine their magnetomechanical properties. For that

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purpose, the manufacturing procedure was developed which made it possible to produce magnetically polarized MRE with thermoplastic matrices of various plasticity. Their properties were tested on a dedicated test stand, described in detail in authors' previous publications [2, 6].

3. Manufacture of Anisotropic Magnetorheological Elastomers

The properties of magnetorheological elastomers depend mainly on their chemical composition and particle alignment. In this chapter different components are discussed and the manufacturing process is described for the selected compositions.

3.1. Matrix

The most popular materials used as MRE matrices are silicone or natural rubbers [3, 5, 7]. Since these materials are not recyclable, there is no possibility of reprocessing once the matrix is cured. That is why a thermoplastic elastomer Téfabloc TO 222 was selected as matrix. The material was purchased in the form of granules, several mm in size. The elastomer was previously used by the authors and its high mechanical strength and low hardness (see Table 1) yielded satisfactory results [2, 6].

Téfabloc TO 222 properties [10] Table 1

Unit	**Value**
Hardness [Shore A]	30
Density [g/cm^3]	0.89
Tensile strength [MPa]	4.5
Ultimate elongation [%]	800

3.2. Magnetic Particles

If maximum magnetorheological effect is to be obtained, magnetic particles should have high magnetic permeability and saturation magnetization [1]. Also the size and shape of the particles strongly affect the properties of the whole composite. The highest magnetorheological effect is achieved for magnetic particles several dozen micrometres in size, with irregular shape [5]. ASC 300 iron powder from the Höganäs AB company [8], which fulfilled most of these criteria, was selected as magnetic filler. Performed examinations revealed that particles have a porous surface, irregular shape (Figure 1) and, on average, measure about 42 μm [4].

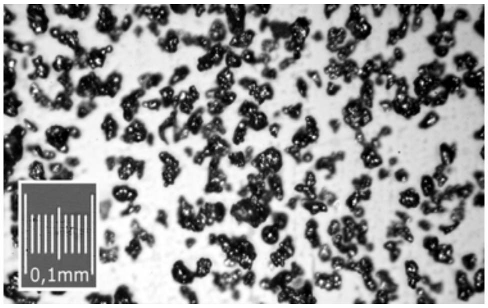


Fig. 1. *ASC 300 iron powder*

3.3. Other Components

Additives can significantly change the properties of magnetorheological elastomers by: improving interactions between the matrix and magnetic filler (e.g. silanes), changing the plasticity of the composite (plasticizers), improving the miscibility of the components or preventing ferromagnetic iron particles from oxidation (antioxidants). Previous investigations revealed a weak influence of silanes on the obtained magnetorheological effect [6]. Therefore, the final test samples included only an additive in the form of a plasticizer (paraffin oil).

3.4. Composition of Test Samples

To achieve maximum MR effect in a magnetorheological composite, the proportions of individual components must be carefully selected. The content of magnetic particles should be as high as possible. The limit value, known as the critical particle volume concentration (CPVC) can be calculated [5]. For ASC 300 iron, it amounts to 36.5%. Since this value makes an assumption that particles are dispersed uniformly within the matrix, it should be lowered for anisotropic MRE. Various contents of magnetic particles were tested and the final volume fraction of ASC 300 iron powder was set to 35%. The densities of the matrix and the plasticizer were similar. That is why composition modifications were made in such a way that the iron volume fraction remained constant while the content of the other two components changed. Five different sample types were produced, as shown in Table 2.

3.5. Manufacturing Process

The manufacture of anisotropic MR elastomers consisted of several operations. First, all components were mixed together at high temperature (processing temperature of the matrix material) in the Plasti-Corder Lab-Station mixer made by Brabender company[9]. When the mixing chamber (Figure 2) was heated the blades started counter-rotation towards each other with a constant speed of 60 rpm.

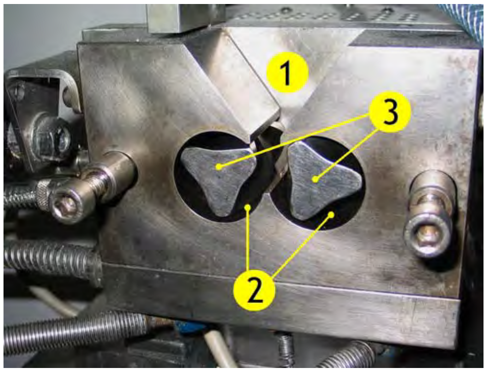


Fig. 2. *Mixing chamber: 1 – inlet, 2 – mixer bowl, 3 – blades*

Simultaneously, the torque and stock temperature were measured and recorded as a function of time. The resulting diagram, the so-called plastogram, is shown in Figure 3. The diagram explains the mixing procedure: in the beginning, the matrix polymer is poured into the mixer bowl (0-1section in Figure 3). After several seconds the ASC 300 iron powder is added (2-3). Soon after, a half of the paraffin oil (plasticizer) is poured into the bowl (4) and then the other half (4’). Finally, the components are mixed together for a few minutes (4’-5).

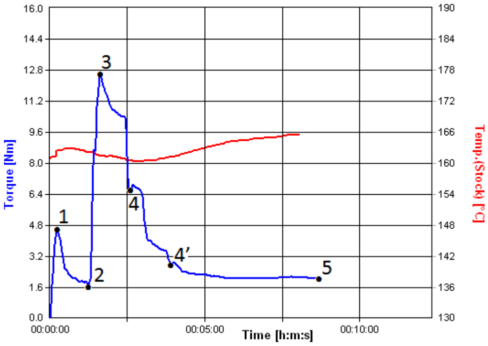


Fig. 3. *Exemplary plastogram from the Brabender mixer*

Chemical compositions of the test samples Table 2

Specimen type	P1	P2	P3	P4	P5
ASC 300 [g]	125	125	125	125	125
ASC 300 [vol%]	35	35	35	35	35
Téfabloc [g]	22.6	21.6	20.8	20	19
Paraffin oil [g]	3.4	4.4	5.2	6	7

The next stage of the MRE manufacture was press moulding. The material obtained from the mixer was placed in an aluminium mould and pressed until the material reached the processing temperature of the matrix. In this way, the matrix became viscous and the composite filled the mould completely. The hot mould was then removed from the press and slowly cooled between two strong (0.5 T) permanent magnets with a magnetic polarization vector perpendicular to the sample (Figure 4). As the matrix material was still viscous, the magnetic field caused the iron particles to arrange themselves into chains parallel to the field lines. After several minutes the composite cooled down and its anisotropic structure became permanent.

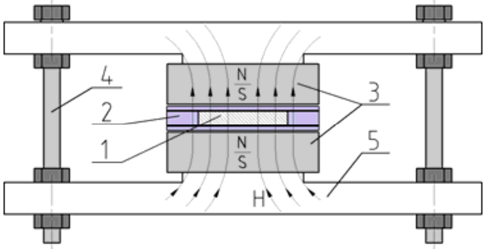


Fig. 4. *Magnetic circuit: 1 – MRE, 2 – aluminium mould, 3 – magnets, 4 – adjustable bolts, 5 – external magnetic core, H – magnetic field lines*

The composite in the shape of a 4 mm-thick plate was removed from the mould. The anisotropy resulting from magnetic polarization was particularly visible on the edges of the moulded pieces (Figure 5). To avoid inhomogeneities in the material, those edges were cut off and MRE plates measuring 40×40×4 mm were obtained.

To prepare the material for testing, each two MRE plates were glued in between clamping plates made of fibreglass reinforced epoxy laminate. A scheme of the final test sample is shown in Figure 6.

Fig. 5. *The edge of an MRE moulding with needle-shaped particle structures resulting from magnetic polarization*

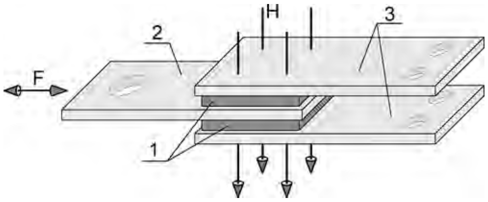


Fig. 6. *Test sample. 1 – MRE, 2 – clamping plate (movable), 3 – clamping plate (stationary), F – loading force vector, H – magnetic field vector*

4. Testing methods

Anisotropic MR elastomers were examined on a dedicated test stand (see Figure 7) which was also used in the authors' previous investigations [2, 6].

Test samples were subjected to cyclic shearing through the movement of a middle clamping plate (see Figure 6). The plate was moved by a piston of the MTS machine. The test stand was also equipped with a magnetic circuit (Figure 7). The field generated by the circuit acted on MRE samples in the same way as during their manufacture, i.e. in the perpendicular direction (see Figures 4 and 6).

The testing procedure was similar to the one used in [2]. The loading frequency was constant (1 Hz). After each 100 cycles the magnetic field strength H was increased by 25 kA/m (from 0 to 100 kA/m). Then, after

500 cycles, the strain amplitude γ_a increased by 6.25×10^{-3} and the procedure was repeated. The testing lasted for 2000 cycles which corresponded to 4 strain amplitudes (0.00625-0.025). The test stand enabled registration of results in the form of data containing displacement and force values in MRE as a function of time. For each displacement amplitude and each magnetic field strength a single cycle was cut out and processed using the HP VEE software. In this way stress-strain (τ-γ) graphs, in the form of hysteresis loops, were obtained.

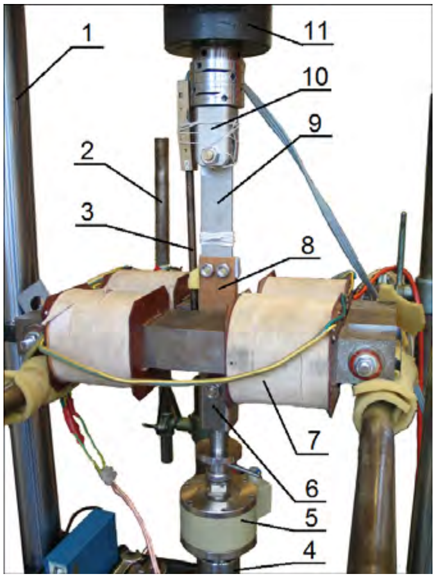
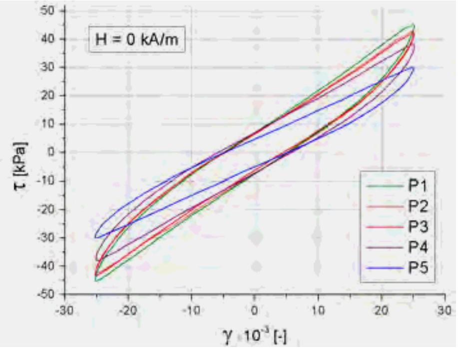


Fig. 7. *Test stand. 1 – MTS machine, 2 – support, 3 – Hall probe, 4 – piston, 5 – PCB force sensor, 6 and 10 – clamping jaws, 7 – magnetic circuit, 8 – sample clamping plates, 9 – non-magnetic fixture, 11 – MTS force sensor*

5. Results and Discussions

Hysteresis loops for all MRE types are shown in Figure 8 for extreme magnetic field values (0 and 100 kA/m) and maximum strain amplitude $\gamma_a = 25\times10^{-3}$.

a)



b)

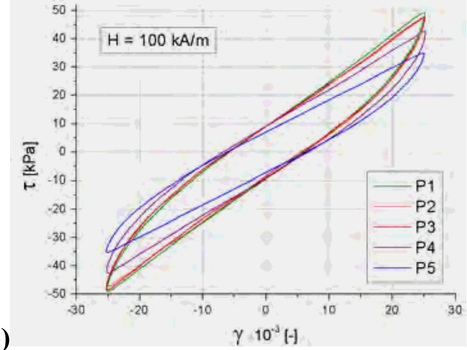


Fig. 8. *Hysteresis loops without magnetic field (a) and with maximum field (b)*

It is visible that maximum stress values are higher for the samples which contain less plasticizer (see Figure 8a and Table 2). Furthermore, the application of external magnetic field increases the stress values, regardless of the sample type (Figure 8b), which might be recognized as magnetorheological effect in the material.

The area of hysteresis loop in the stress-strain system shows the amount of dissipated energy per unit of material volume. Therefore, the MR effect in anisotropic MRE may be expressed by their ability to dissipate energy, by the percentage value of hysteresis loop area change δW [2, 6]. This parameter is calculated for the two extreme magnetic field values (0 and 100 kA/m) and thus describes how much a hysteresis loop area changes under the influence of the field. Average δW values for all MRE types are shown in Figure 9. One can notice that the results are strictly dependent on the plasticizer content. The highest δW values are obtained for the softest MRE (P5-type sample) while the lowest loop area changes are observed in the composites with low plasticizer content (P1 and P2).

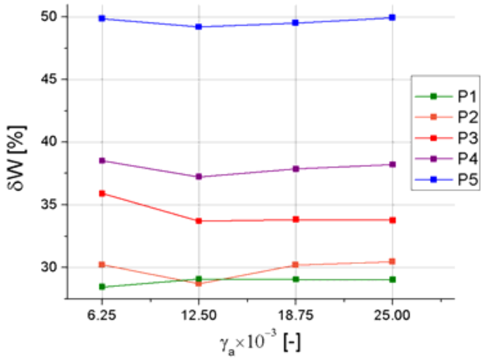


Fig. 9. *Average percentage values of hysteresis loop area change (δW) for various strain amplitudes (γ_a)*

6. Conclusions

Anisotropic MR elastomers with different plasticizer content were manufactured and their magnetomechanical properties tested. Magnetorheological effect was observed as changes in material stress occurring under the influence of external magnetic field. The results revealed that the MR effect expressed as the hysteresis loop area change is proportional to the plasticizer content and is the highest for the softest composites.

Acknowledgements

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