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Research articles

Influence of the size of magnetic filler particles on the properties of hybrid magnetic elastomer with magnetically hard filler

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ABSTRACT

The magnetic properties of hybrid magnetic elastomers (HME) featuring a type of magnetorheological elastomer filled with high-coercivity (a.k.a. magnetically hard) particles have been studied. Introduction of magnetically hard components into the formula significantly modifies both magnetic and rheological parameters of the composite. An additional factor having an influence on the overall behavior of the elastomer is based on the properties of the powder used as filler determined by its dispersion degree. Impregnation of the polymer matrix with a magnetically hard powder leads to a complex relationship between the magnetization and elasticity of the material and magnetic field as compared to the behavior demonstrated by composites based on magnetically soft filler, which is determined by the rotational motion of the particles inside the sample. Such a material exhibits asymmetrical magnetization hysteresis loops.

1. Introduction

Magnetic elastomers containing magnetically hard filler have recently become an object of scientific interest. As has been demonstrated in previous experiments dedicated to studying their magnetic and magnetorheological properties, these materials are capable of changing their parameters either after being magnetized or during being influenced by a magnetic field exhibiting complex relationships [1–6]. At the same time, industrial fabrication of this type of magnetically controlled elastomers requires an understanding and knowledge of their specific properties.

Determined by the characteristics of the filler and the polymer matrix [7–12], the magnetic properties of the composite materials may, as has been discovered earlier, significantly differ from those of the initial particulate material. These differences demonstrate a strongly nonlinear relationship with the magnetization of the filler and grow faster than might be expected on the assumption that this function is linear. In such materials, their magnetization, remnant magnetization, and coercivity may vary resulting from magnetic field application. Such magnetic elastomers containing both magnetically hard filler and soft components are conventionally called ‘hybrid magnetic elastomers’ (HME) [11] and can be used in both damping devices [1–6] and acceleration sensors [13–16]. Investigation of the influence of the particle size of the material used as filler on the overall set of features of the was the purpose of this research.

Indeed, the condition of the powder is responsible for certain behavioral specifics of the composite. Therefore, in the set of experiments carried out, attention was given to the influence the dispersion degree of the filler had on the overall behavior of the elastomer. In light of the fact that the magnetic features of magnetic particulate matters may vary with particle size, which has connection with the demagnetizing factor, in our work we operated with an NdFeB-alloy powder sieved into fractions with grain sizes being below 40 µm, in the range 40–80 µm, and above 80 µm, on the basis of which our samples were fabricated.

Although magnetic elastomeric composite materials filled with magnetically soft particles have been studied quite profoundly, their analogues containing magnetically hard components remain to be fresh ground.

Keeping in mind that a general composite may contain a mixed filler, for the purpose of uncovering the special features brought in by magnetically hard particles, all experimental HME samples were prepared with no magnetically soft component. At the same time, future studies of HME utilized in damping units assume using magnetically soft powders as additional additives.

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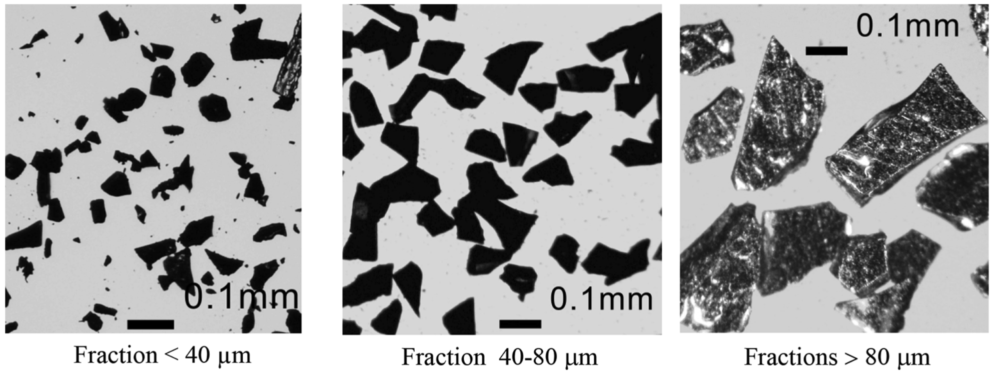

Fig. 1. Photografic images of magnetic particles of the NdFeB-alloy from different fractions of the powder.

2. Samples and methods

Experimental HME samples were fabricated using the two-component SIEL-254 silicone-elastomer compound, a product of Russian State Scientific Institute for Chemical Technologies of Organoelement Compounds. The SIEL-254 components are initially liquid and solidify as a result of the cross-linking process occurring between the hydride- and vinyl-containing parts when mixed together with following thermal treatment. The softness of the forming polymer was controlled by the addition of Silicone Oil M100 used as a softener. The magnetic material used as filler was a commercial YMM-Q-grade NdFeB-alloy powder exhibiting magnetically hard properties. This powder having particles with irregular geometries and sizes ranging 1–300 μm was sieved into three fractions (Fig. 1), which were used for the preparation of the corresponding HME samples. In order to avoid aggregation and make the surfaces of the particles hydrophobic and thus provide a better compatibility with the polymer, the powder was preliminarily subjected to modifying with Silicone Oil M100. Taken in an amount that the overall weight concentration in the samples be ~80%, the filler was then mechanically stirred into the liquid matrix. After degassing the suspension, it was distributed among moulds and cured at ~100 °C. The samples were prepared as cylinders being 14 mm in diameter and 4 mm in height and plate-like. Measurements of their rheological properties were carried out on a rheometer (HAAKE MARS II, Thermo Fisher Scientific) As a result, the shear modulus for samples: (1–40 μm) – 250 kPa, (40–80 μm) – 200–220 kPa (more than 80 μm) – 180 kPa was determined The polymer matrix was the same for all composites.

Measurements of their magnetic properties were carried out on a vibrating-sample magnetometer (Lake Shore 7407, USA). As a result, magnetization curves M(H) were recorded.

3. Results and discussion

3.1. Magnetic properties of the powder

The magnetic characteristics of the YMM-Q-grade NdFeB-alloy powder were recorded by means of subjecting the samples to a sequence of full hysteresis loop measurements with the amplitude monotonously increasing from loop to loop from 2 to 20 kOe with a step of 2 kOe. Fig. 2 presents a typical series of loops obtained as a result of magnetizing the powder.

After the commercial powder was separated into three fractions, such series of hysteresis loops were recorder for every one of them.

The data obtained were the source, out of which coercivity and remnant magnetization values were extracted.

These results are crucial for the determination of the working conditions for the magnetic elastomer, which may retain working capacity in different fields.

Fig. 3 presents coercivity as a function of the strength of the magnetizing field for every fraction of the powder.

The coercivity values corresponding to the branches of the hysteresis loop match up almost perfectly at all magnetizing fields and independently of the fraction selected. It is demonstrated by curve 1′ shown with a dash-line at the top of the graph.

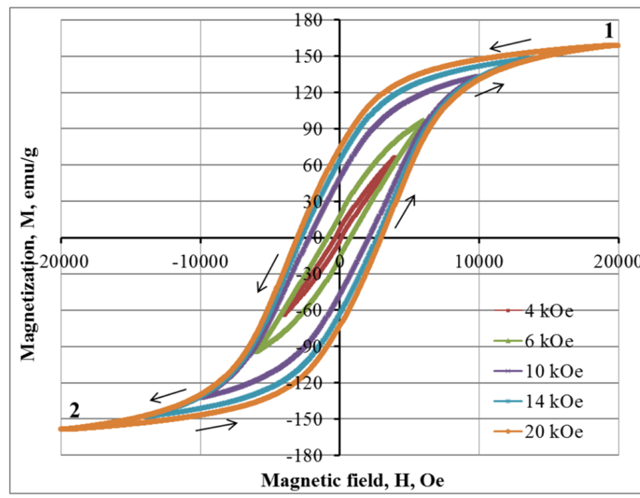

Fig. 2. Magnetization of the YMM-Q-grade NdFeB-alloy powder as a function of magnetic field. On the way from point 1 to point 2 and back, i.e. along the descending and ascending branches of the hysteresis loop, the sample is subjected to the first and second re-magnetizing procedures (polarity reversals).

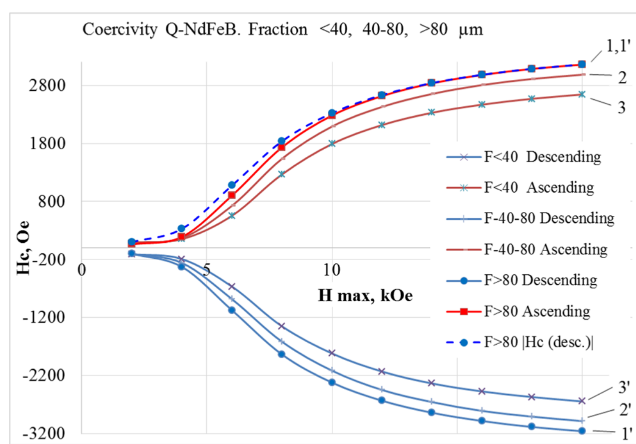

Fig. 3. Coercivity of the YMM-Q-grade NdFeB-alloy powder as a function of the strength of the magnetizing field. Average particle size: lines 1, 1′ – fraction above 80 μm; lines 2, 2′ – fraction 40–80 μm; lines 3, 3′ – fraction below 40 μm (lines 1′ 2′ 3′ correspond to the descending branch of the hysteresis loop).