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Magnetodeformational effect and effect of shape memory in magnetoelastics

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Abstract

In the present work we consider new magnetocontrolled elastic composite materials produced by dispersing ultra-fine and larger magnetic particles in polymer matrix based on natural or synthetic rubber. The giant magnetodeformational effect, effect of a magnetic field influence on the elastic properties and effect of shape memory in magnetoelastics are discussed.

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1. Introduction

In this work we consider new magnetocontrolled elastic composite materials (magnetoelastics) produced by dispersing ultra-fine and larger magnetic particles (from 10 nm to 3 μm) in a siloxane rubber oligomer in the presence of a surfactant and plasticizers [1,2]. These materials are more soft than classical magnetoelasts [3–5]. In this paper the giant magnetodeformation effect (which consists in the deformation of samples exposed to an external magnetic field), effect of a magnetic field influence on the elastic properties and effect of shape memory in magnetoelastics are discussed.

2. Results and discussion

We experimentally studied the elongation of ribbon-shaped and cylindrical magnetoelastic samples in non-uniform magnetic field of the electromagnet. It was found that in magnetic field these materials have large value of elongation (to 200–300% from the initial length) and after elongation they completely restore their initial shape when we turned off magnetic field. In magnetic field the shape of sample is determined by equilibrium of magnetic and elastic forces. Fig. 1 shows a typical experimental results which give the dependences of elongation as function of current intensity (initial length of samples is 40 mm). In our case mean value of magnetic field and the value of the field gradient are proportionate to value of current and for current $I = 1.4\,\mathrm{A}$ are 1000 Oe and 200 Oe/cm accordingly.

We also studied the influence of magnetic field on the elastic properties of magnetoelastics. In our experiment we measured the relative elongation ΔX of cylindrical and ribbon samples placed in uniform magnetic field H and without H on stretching force F (stretching force $F \perp H$). Young's modulus was calculated from the dependencies of stress σ on Δx. It was found that the application of magnetic field leads to a substantial increase in the Young's modulus. A theoretical model which describes the effect of magnetic field influence on the elasticity is proposed in Ref. [2]. In this theoretical model the magnetic field causes the particles structurization, which results in formation of regions compressed by forces of magnetic dipole–dipole interaction.

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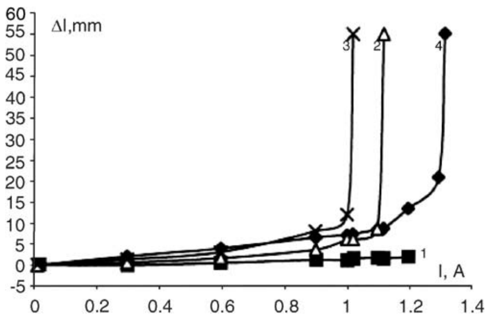

Fig. 1. The elongation Δl by a nonuniform magnetic field created by an electromagnet as a function of current intensity I for magnetoelastics with iron particles size 110 Å (1), 300 Å (2), 2 μm (3) and with magnetite particles size 0.2 μm (4).

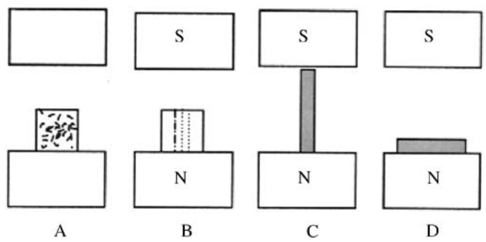

Fig. 2. The scheme of experiment: (A) initial state without magnetic field, (B) initial state in field, (C) stretched state and (D) compressed state in field.

In general case external mechanical force can change magnetoelastics shape but the sample restore initial shape when mechanical force remove. However, in the case, when magnetoelastics is very soft and concentration magnetic particles is very large, stretched or compressed samples may preserve this new shape in magnetic field and restore initial shape only when we turn off magnetic field. The scheme of experiment is in the Fig. 2.

The scheme shows that initial sample (A) changes internal magnetic structure and does not change shape (see B) when magnetic field is included. However, sample (B) after mechanical extensibility (C) or compression (D) in magnetic field direction, reserves new shape. Only when we turned off magnetic field the sample restore initial shape (A). This new effect of pseudo-plasticity in magnetic field or shape memory effect consists in irreversible change of sample shape in magnetic field and completely restore initial shape when we turned off magnetic field. This effect may be explained as follows. It is known that the magnetic particles in magnetoelastics are aligned into chains by applied magnetic field [2]. As a result of this phenomenon internal friction increased. External mechanical force can overcome internal friction and change shape of sample at one's own choosing. Dipole–dipole interaction of magnetic particles in chains reserves sample shape in magnetic field. Every time external mechanical force breaks initial chains of

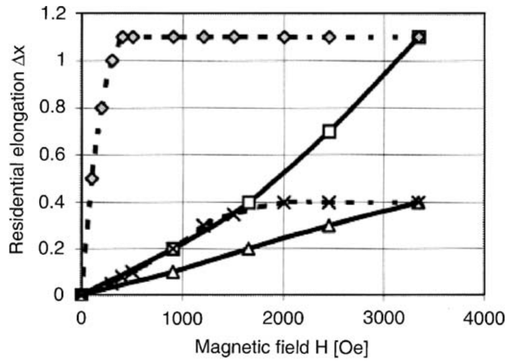

Fig. 3. Dependences of the maximum residual elongations ΔX on magnetic field for soft (□) and more hard (△) magnetoelastics, on base iron particles. (◇) and (×) show dependences residual elongations of sample in process of magnetic field decrease to zero.

magnetic particles in magnetic field but magnetic field forms new long chains for case of extensibility or short chains for case of compression (see Fig. 2). And every time dipole–dipole interaction of magnetic particles in new chains reserves new sample shape in magnetic field. Only when we turned off magnetic field forces of dipole–dipole interaction decreased and initial shape of sample was restored by elastic forces of polymer matrix.

Fig. 3 gives dependences of as much as possible residual elongations of mechanical stretched sample on value of magnetic field. For a example, dependences for very soft with Young's modulus $E = 2$ kPa and for more hard with $E = 16$ kPa magnetoelastics are presented. In Fig. 3 we can see that the application of greater magnetic field leads to greater residual elongation of sample.

3. Conclusions

It was found that in magnetoelastics the application of a magnetic field leads to appearance giant magnetodeformational effect, to a considerable rise in Young's modulus and to appearance effects of pseudo-plasticity and shape memory in soft magnetoelastics with great concentration of magnetic particles.

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